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SEARCH AND RESCUE

TARGET DETECTION EXPERIMENT - CANSO BANK, 1987

SEPTEMBER, 1988

PREPARED FOR THE TRANSPORTATION DEVELOPMENT CENTRE,
POLICY AND CO-ORDINATION GROUP, TRANSPORT CANADA

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16. Abstract

A ship-based search and rescue (SAR) detection experiment took place off Nova Scotia on the Canso Bank in October and November 1987. The primary objectives were to collect visual sweep width data for Canadian SAR vessels in typical Canadian east coast conditions, and to determine the sweep width improvement achievable using sophisticated SAR technology. The ship used was the CCGS "Sir William Alexander" and the targets were 4-man orange and 6-man yellow life rafts complete with canopies. Daylight visual searches, night visual searches for canopy lights, night vision goggle searches for unilluminated rafts, and marine radar searches for radar enhanced and unenhanced life rafts were undertaken. The derived sweep widths for searches were two to three times that given in the current national SAR manual; this is attributed to the lookout's height of eye and the stability of the vessel. Sweep widths for SAR radar transponders were almost 9 nmi. Radar operators were found to concentrate on the forward and starboard sectors. Results of experiments using navigation/radar simulators prior to the field experiment indicate that radar operator detection performance decreased significantly after one hour on duty. A number of recommendations are made for changes to operational sweep widths and further research.

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16. Résumé

Des opérations expérimentales de recherche et de sauvetage ont été menées en octobre et novembre 1987 au large des côtes de la Nouvelle-Écosse (Blanc de Canso) à bord d'un navire de la Garde côtière canadienne. L'objectif principal de ces expérimentations a été de rassembler des données permettant de calculer la largeur des circuits de ratissage dans les conditions propres à cette zone marine et de déterminer les améliorations que rendraient possibles diverses techniques avancées de R-S. Les expérimentations ont été effectuées à bord du Sir William Alexander et les cibles ont été des radeaux de sauvetage 4 et 6 places équipés de tentes de couleur orange et jaune, respectivement. Des recherches visuelles diurnes, nocturnes (radeaux éclairés), des recherches avec lunettes de vision nocturne (radeaux non eclaires); des recherches avec le radar de bord (radeaux avec ou sans dispositifs de visibilité radar) ont été faites. Les largeurs tirées des expérimentations ont été, toutes choses égales, le double ou le triple de celles du Manuel national de recherche et de sauvetage. Ces résultats soulignent l'importance des paramètres de la hauteur d'observation et de la taille du navire. Les largeurs dérivées des recherches radar avec transpondeurs ont été non loin de 9 milles marins. Il a été constaté que l'attention des opérateurs radar avait tendance à se concentrer sur les quadrants avant et tribord. Les expérimentations sur simulateur de navigation radar, faites avant celles en mer, montrent que la vigilance de l'opérateur radar fléchit considérablement au bout d'une heure de service ininterrompu. Le rapport fait plusieurs recommandations concernant les modifications à apporter aux largeurs de ratissage et les expérimentations à venir.

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EXECUTIVE SUMMARY

Present search planning by the Canadian Coast Guard (CCG) employs detection guidance derived from experiments carried out by the United States Coast Guard (USCG). These detection experiments, primarily visual, were conducted off the mid-Atlantic coast of the United States in sea states and general weather conditions predominantly better than those typically found off the east coast of Canada. As a result, it is believed that the basis upon which sweep width is computed may not be entirely appropriate for searches conducted in Canadian waters. Consequently, a major ship-based search and rescue (SAR) target detection project was undertaken culminating in a detection experiment in October and November, 1987, off Nova Scotia on the Canso Bank. The targets were four and six-man canopied life rafts, some equipped with radar enhancement devices. The primary objectives were to:

1. obtain visual sweep width data for Canadian SAR vessels in typical Canadian East Coast conditions;

2. augment the USCG data base on visual detection information for sea states 3 to 5;

3. determine sweep widths for standard ship radars against unenhanced and radar reflector equipped life rafts; and,

4. determine the sweep width improvement that might be achieved using marine radars with more sophisticated signal processing capability.

The project was divided into four phases:

Phase I - Initial Preparatory Work
Phase II - Detailed Experiment Planning
Phase III - Field Experiment
Phase IV - Data Reduction and Analysis.

The primary objectives of Phase I were to:

1. identify sources for forward-looking infrared (FLIR) systems and marine radar systems equipped with sophisticated signal processing capability;

2. determine the degree and type of USCG participation in the experiment;

3. identify a suitable navigation system;

4. identify the ship, location, and time frame for the experiment; and,

5. assess the feasibility of using CCG radar simulators for conducting radar detection experiments and for investigating certain human factors that impact on the operation of a marine radar search.

The results of Phase I were as follows:

1. It was recommended that FLIR systems currently available on the market not be tested at this time. A Sperry RASCAR and a Raytheon Pathfinder ST radar were selected as potential radar systems.

2. The USCG agreed to place at least one representative on board the vessel during the experiment, to supply a LORAN-C buoy complete with a VHF receiver system, and to provide a number of radar reflectors.

3. A custom-designed differential LORAN-C radionavigation system was recommended for use during the experiment.

4. The CCGS "Sir William Alexander" was selected as the experiment vessel and the location designated for the project was the Canso Bank area off Nova Scotia. A suggested start date for the experiment was September 15, 1987.

5. The navigation radar simulators at the CCG College in Sydney, Nova Scotia, and at the Transport Canada Training Institute (TCTI) in Cornwall, Ontario, were found to be inadequate for conducting simulated radar detection search and rescue experiments. The TCTI simulator was considered suitable for the investigation of certain human factors relating to electronic searches using marine radar.

The primary objectives of Phase II were to:

1. develop a detailed field experiment schedule;

2. develop a detailed experiment methodology;

3. develop the navigation system for use during the experiment; and,

4. investigate significant human factors related to operating a marine radar in a search operation through the use of the TCTI navigation/radar simulator.

The results of Phase II were:

1. A schedule was developed which involved the ship departing port for the experiment on October 15, 1987. A Raytheon radar was to be installed in the first week of November, 1987. The experiment was scheduled to end on November 30, 1987.

2. The experiment methodology selected was that employed by the USCG in similar search and rescue detection experiments.

3. A custom differential LORAN-C navigation system was developed which utilized a moored LORAN-C buoy with an on board receiver, an Internav LORAN-C receiver, the ship's satellite navigation receiver, a Compaq Portable II microcomputer system, and a NORDCO Limited Single Board Computer.

4. The human factors experiment undertaken using the navigation/radar simulator facilities at TCTI indicated that, in general, radar operators concentrated more on the starboard and forward sectors of the Plan Position Indicator (PPI) display, they concentrated on the area around the edge of the sea clutter, there was a detection performance drop after about one hour, and a 5- to 10-minute break after two hours resulted in only a short-lived improvement in performance.

In Phase III of the project, field equipment was acquired and tested and the experiment was conducted.

Mobilization of the ship for the experiment was carried out at the CCG base in Dartmouth, N.S., from October 13 to 15, 1987. The ship departed on October 16, 1987, arriving in the experiment area early on Saturday, October 17, 1987.

Two instrument and twenty target moorings were deployed initially and the navigation system hardware, software, and procedures were checked for proper function. The search targets, secured to the moorings, were either 4 or 6-man life rafts equipped with standard canopy lights. At any specific time approximately 10 life rafts were deployed. The radar reflectivity of some of the rafts was enhanced by suspending a 2 square metre (m^2) Luneburg lens X-band radar reflector from the canopy tube. Other targets included the radar reflectors mounted on spar buoys at canopy height and Mitsubishi X-band radar transponders deployed on the ocean surface.

Between October 19 and October 31, a number of radar detection tests were conducted and a total of 19 search patterns were run. Visual searches were conducted during the day as well as at night. Electronic searches, using a Sperry 4016 X-band marine radar and a Sperry 340 radar, were also conducted. Target detections during the searches were made by CCG personnel. Seamen and leading seamen acted as visual lookouts while officers (primarily supernumerary personnel) undertook the radar watches.

The ship returned to the CCG base in Dartmouth on November 1 and remained there until late on November 5, 1987. Between November 1 and 5, a Raytheon Pathfinder ST raster display marine radar was installed on the ship. The ship returned to the experiment area on November 6. From November 9 until November 20, 12 more visual and radar searches were conducted in the Canso Bank area. Night vision goggles, provided

by the USCG, were used during two night searches. Radar searches were conducted using the ship's standard Sperry radar and the Raytheon Pathfinder ST unit. The experiment ended on November 24, 1987.

Phase IV involved data reduction, analysis, compilation of results, and preparation of the final report on the project. The data reduction involved semi-automated procedures for track re-construction and compilation of files of valid detections and opportunities for each target type and sensor along with the necessary ancillary information. The maximum log likelihood technique, which is also utilized by the USCG, was employed for the analysis of the daylight visual searches, the visual night searches for canopy lights, the night vision goggle searches, and the radar searches for SAR radar transponders. The maximum log likelihood technique was not applicable to the radar searches for passive targets. A linear logistics model was used to determine the significance of all the regressors (except lateral range) for the passive radar targets. A cubic spline fit was used to derive the probability of detection as a function of lateral range in order to compute sweep width. The 90% confidence level was used to determine whether a regressor (significant wave height, target type, visibility, etc.) was significant.

Sweep widths for daylight visual searches were found to be dependent on lateral range, visibility, significant wave height, and target type (four- or six-man life raft). In a comparison with the visual sweep width table now employed by the CCG, under comparable conditions the sweep widths derived in the experiment were greater by a factor of approximately 2 to 3 in all cases. The results show the merits of using large and stable vessels for SAR operations.

The night visual search results showed that lateral range was the only significant factor and the subsequent sweep width was 2.2 nautical miles (nmi). Although this is based on a small data set, the data spread is low and some confidence can be placed in the results. Wind speed and significant wave height were just below the 90% significance limit. With a larger data set either or both of these factors may become significant. Sweep widths for this type of target have not been reported previously. However, based on this result there is some indication that the sweep width estimates now used for hand flashlights and strobed life jacket lights may be too high.

The night vision goggle search results showed that lateral range was again the only significant factor. As with the night searches for lights, both windspeed and significant wave height were just below the significance limit. The sweep width was found to be 1.4 nmi. This is based on a small data set that has considerable spread in it and therefore low confidence should be placed in the actual sweep width derived. The goggles were meant to function with some sky light available; however these searches were conducted in 100% cloud cover.

The analysis of the radar search results showed that lateral range was the only significant factor. Sweep widths derived from the

standard Sperry 4016 radar detection data were effectively 0.0 nmi for empty life rafts while for the Sperry 340 and the Raytheon Pathfinder radars, sweep widths were 0.4 and 0.3 nmi, respectively. For life rafts with 2 m^2 Luneburg lens reflectors mounted inside (which approximates four men in the life raft) the Sperry 4016 detection data resulted in a sweep width of 0.6 nmi. For the same targets, sweep widths derived from the Sperry 340 radar detection data resulted in a sweep width of 0.5 nmi. For the reflector mounted at canopy height, the Raytheon radar had a sweep width of 1.8 nmi and the Sperry 4016 sweep width was 1.6. The radar transponder had sweep widths of 8.8 and 8.7 nmi on the Sperry 4016 radar and the Raytheon radar, respectively. Polar diagrams of the distribution of detections by range and bearing showed more detections forward than aft and a bias to the starboard side. The effect of the mast shadowing on the Raytheon radar was evident from the total lack of detections on the starboard quarter.

The radar sweep widths, with the exception of those for the radar transponder, were derived using a non-standard technique and almost all the probably of detection versus lateral range curves show a substantial drop in probability at or near zero lateral range.

Obscuration of the radar targets by ocean waves was detrimental to the detection of the passive targets. The benefit of the higher reflector height is evident from the sweep widths derived for the reflector mounted at life raft canopy heights. The presence of waves was of much less importance for the transponder as it only had to be interrogated once in a number of sweeps to be detected.

The performance of the more sophisticated radars clearly shows that new processing schemes are directed more towards producing a clearer screen (reducing false alarms) than substantially improving weak target detection capability. The ability to track weak targets inside the sea clutter zone using the Raytheon Pathfinder ST radar clearly shows the improvement that might be achieved by using more sophisticated clutter reduction schemes.

Radar shadow areas on ships and operator look direction biases will result in the search area around any ship being distorted and unique to that vessel.

Radar operator motivation was a concern during the experiment. This may have resulted in the measured sweep width being biased somewhat low.

The following recommendations are made as a result of the experiment.

1) For ships comparable to the CCGS "Sir William Alexander" searching for four-man orange canopy and six-man yellow life rafts in visibilities greater than 8 nmi, winds up to 40 knots, significant wave heights up to 2.5 to 3.0 metres (m) and no precipitation, sweep widths based on the results of this experiment should be

used. All other vessels should continue to use the visual SAR sweep width tables provided in the National Search and Rescue Manual.

2) Another visual detection experiment utilizing the CCGS "Sir William Alexander" or a sister ship should be undertaken in conditions which will allow derivation of the reductions expected when operating in visibilities of less than 8 nmi and in significant precipitation. The dependency of life raft size and colour should be investigated as well.

3) A visual detection experiment should be undertaken utilizing a vessel of the same size but less stability, the CCGS "Alert", for example.

4) A visual detection experiment should also be undertaken using a smaller class of vessel which is still significantly larger than a USCG SAR vessel (the CCGS "Jackman", for example).

5) A joint program between the USCG and the CCG should be initiated in order to develop and refine theoretical models for visual sweep widths for various types and sizes of vessels operating in a wide variety of conditions and searching for various targets.

6) For ships comparable in size and stability to the CCGS "Sir William Alexander" searching for four- and six-man illuminated life rafts at night in visibilities greater than 10 nmi, winds up to 40 knots, significant wave heights up to 2.5 m and no precipitation, a sweep width of 2.2 nmi should be used.

7) The estimated sweep widths for hand flashlights and life jacket strobe lights given in the National Search and Rescue Manual should be reduced to 2.2 nmi until actual experimentally derived data are available.

8) More night search experiments for life rafts equipped with lights should be undertaken.

9) Discussions should be held with life raft manufacturers regarding their plans for possible new lens/light/battery pack combinations so that these can be incorporated into future experiments.

10) It is recommended that a more extensive experiment be conducted to test newer models of the night vision goggles against illuminated and unilluminated targets. Following the experiment the ship's captain should provide an assessment of these devices in terms of the operational problems encountered.

11) For ships of similar size and having similar radar configurations to that of the CCGS "Sir William Alexander" conducting a radar search, a sweep width of about 0.25 nmi should be used for four- and six-man life rafts in winds up to 30 knots, significant wave heights up to 2.5 to 3.0 m, and no precipitation.

12) More SAR radar transponder experiments should be undertaken.

13) Discussions with life raft manufacturers should be undertaken to determine possible techniques for effectively incorporating passive radar reflectors and transponders in the life raft canopy or at some height above the canopy.

14) For any future experiments involving radar searches, it is recommended that the radar operators be assigned to the experiment for a maximum of one week each.

15) CCG and TDC should consider initiating solicitations of interest for the development in Canada of a SAR radar transponder which has, at a minimum, the same performance characteristics as the unit tested during this experiment.

16) CCG and TDC should actively support research and development activities directed toward the design of radar signal processing units which may be interfaced to existing radars and specifically designed to significantly improve their weak target detection capability.

17) During CCG marine radar search operations, radar operators should be relieved after one hour. Operators should be given a break of at least one hour before returning to radar duty.

18) If any further simulator research is to be undertaken in the area of human factors relating to marine radar search operations, expertise in the area of ergonomics and psychophysics should be utilized.

19) During the planning and the actual conduct of the recommended visual and radar detection experiments, expertise in the area of ergonomics and/or psychophysics should be consulted. Such a person should also participate in the field experiment to observe and record significant human factor effects.

20) An international symposium or workshop should be organized involving government representatives and industrial expertise to familiarize all participants with past and ongoing work undertaken by the various countries, to establish areas of research priority, and to establish a framework where internationally accepted standards and methodologies can be formulated for the derivation of pertinent results.

21) The degree of cooperation that has now been established with the USCG should be nurtured and maintained for any future SAR research.

22) A small airborne radar experiment should be undertaken coincident with the next ship-based SAR experiment. The Litton 504(V)5 radar, now deployed on an Atlantic Airways aircraft, should be the radar tested. The experiment will provide some performance

information and the experience gained will be invaluable in the planning and conduct of a future airborne detection experiment.

23) A major airborne experiment involving airborne synthetic aperture, side-looking, and surveillance radars should be planned for the March - April 1989, time frame off the coast of Newfoundland.

24) It is recommended that an experiment be undertaken to test Emergency Position Indicating Radio Beacons (EPIRB).

SOMMAIRE

La planification des opérations de recherche et de sauvetage au sein de la Garde côtière canadienne (GCC) s'inspire, pour ses méthodes, des expérimentations faites par la Garde côtière des États-Unis au large de la côte médio-atlantique du pays, et ce dans des conditions d'état de mer et météorologiques de loin meilleures que celles caractérisant les eaux littorales de la côte Est du Canada. Par conséquent, les données utilisées afin de calculer la largeur des circuits de ratissage ne conviennent pas tout à fait dans les eaux canadiennes. C'est la raison pour laquelle un programme ambitieux d'expérimentation de recherche et de sauvetage en mer a été entrepris, aboutissant aux expériences de détection faites en octobre et novembre 1987 au large des côtes de la Nouvelle-Écosse (Banc de Canso). Les cibles étaient des radeaux de sauvetage 4 et 6 places, équipés d'une tente et, dans certains cas, de dispositifs de visibilité radar. Les objectifs fixés à ce programme ont été les suivants:

1. obtenir des données permettant de calculer la largeur des circuits de ratissage en fonction des conditions caractérisant la côte Est du Canada;

2. enrichir la base de données accumulée par la Garde côtière des États-Unis, notamment pour ce qui est des états de mer de 3 à 5;

3. déterminer la largeur des circuits de ratissage avec des radars de bord standard en fonction de la visibilité des radeaux de sauvetage équipés ou non de réflecteurs radar; et

4. déterminer les améliorations que rendraient possibles des radars de bord bénéficiant de moyens avancés pour le traitement des signaux radar.

Le programme était divisé en quatre étapes:

Étape I : Préparatifs
Étape II : Planification détaillée
Étape III: Expérimentation en mer
Étape IV : Réduction et analyse des données

L'étape I visait les objectifs suivants:

1. établir la liste des fournisseurs de systèmes radar de bord et à capteurs infrarouges à balayage frontal (FLIR), bénéficiant de moyens avancés de traitement des signaux;

2. déterminer la nature et le degré de participation de la Garde côtière des États-Unis dans les expérimentations projetées;

3. choisir le système de navigation adapté;

4. désigner le navire à mobiliser, déterminer l'emplacement ainsi que le calendrier des expérimentations; et

5. évaluer la faisabilité d'utiliser les simulateurs radar de la GCC pour les essais de détection radar et la mise en évidence des facteurs ergonomiques en jeu lors des opérations de recherche avec un radar de bord.

Les résultats de l'étape I ont été les suivants:

1. Écarter, pour le moment, les systèmes radar FLIR actuellement sur le marché et arbitrer entre le radar RASCAR de la compagnie Sperry et le radar Pathfinder ST de la compagnie Raytheon.

2. La Garde côtière des États-Unis a accepté d'avoir au moins un de ses spécialistes à bord pour la durée des expérimentations, de fournir une bouée LORAN-C, le récepteur VHF nécessaire ainsi qu'un certain nombre de réflecteurs radar.

3. Recommander l'utilisation d'un système de radionavigation LORAN-C étudié exprès, en vue de la correction des différences de temps.

4. Le navire choisi a été le Sir William Alexander et le lieu des expérimentations, le Banc de Canso, au large des côtes de la Nouvelle-Écosse. Quant à la date, elle a été fixée provisoirement au 15 septembre 1987.

5. Ni les simulateurs radar de la GCC à Sydney, N.-É., ni celui de l'Institut de formation de Transports Canada à Cornwall (Ontario), n'ont été trouvés aptes à simuler des opérations de recherche et de repérage électroniques en mer. Par contre, le simulateur de l'Institut de formation a été jugé capable d'évaluer certains facteurs ergonomiques intervenant lors des opérations de recherche en mer à l'aide d'appareils électroniques, comme le radar de bord.

Les objectifs fixés à l'étape II ont été les suivants:

1. Mettre au point un programme détaillé d'expérimentations en mer.

2. Mettre au point le mode opératoire.

3. Mettre au point le système de radionavigation devant être utilisé.

4. Se servir du simulateur radar de l'Institut de formation de Transports Canada pour mettre en évidence les facteurs ergonomiques significatifs reliés aux opérations de recherche et de repérage en mer à l'aide d'un radar de bord.

Les résultats de cette étape apparaissent comme suit:

1. Le programme mis au point prévoyait l'appareillage du navire devant servir aux expérimentations le 15 octobre 1987 et la mise en place du radar Raytheon durant la première semaine de novembre 1987. Quant aux expérimentations proprement dites, il a été prevu qu'elles se termineraient le 30 novembre 1987.

2. Le mode opératoire retenu a été le même que la Garde côtière des États-Unis avait mis en oeuvre aux fins de ses propres expérimentations.

3. Un système de radionavigation LORAN-C spécialement adapté a été réalisé; il comporte une bouée LORAN-C amarrée et, à bord du navire, un récepteur LORAN-C, un récepteur Internav, un récepteur de signaux de navigation par satellite, un micro-ordinateur portatif Compaq II ainsi qu'un ordinateur monocarte de la compagnie NORDCO.

4. Les expérimentations sur les facteurs ergonomiques faites à l'aide du simulateur de l'Institut de formation de Transports Canada ont montré que, de façon générale, les opérateurs radar ont tendance à se concentrer sur les quadrants avant et tribord de l'écran panoramique de même que sur la zone épousant le contour du clutter en mer. En outre, il a été constaté que la vigilance des opérateurs fléchissait au bout d'une heure environ et qu'une pause de cinq à dix minutes au bout de deux heures apportait seulement un regain de courte durée.

À l'étape III, il a été procédé à l'acquisition du matériel, aux essais de celui-ci et aux expérimentations proprement dites.

L'appropriation du navire a été faite dans le port de Dartmouth entre le 13 et le 15 octobre 1987. Ayant appareillé le 16 octobre 1987, le navire a atteint le site choisi tôt le lendemain matin.

Les travaux ont commencé par le mouillage des amarrages nécessaires à deux bouées et à vingt cibles et par la vérification des systèmes de radionavigation et des procédures correspondantes. Les cibles amarrées étaient des radeaux de sauvetage 4 et 6 places, équipés de feux fixés à la tente. Le nombre de cibles amarrées n'a jamais été inférieur à 10 environ. Certaines d'entre elles ont été équipées d'un dispositif de visibilité radar, à savoir une lentille de Luneberg fonctionnant dans la bande X, de 2 m2 de surface, fixée au sommet de la tente. D'autres cibles ont aussi été utilisées, notamment des bouées avec réflecteurs radar montées sur mâtereau ainsi que des transpondeurs de bande X Mitsubishi, flottant à la surface de l'eau.

Entre le 19 et le 31 octobre, un certain nombre d'expérimentations ont été entreprises et un total de 19 circuits ratissés. Les recherches visuelles ont été faites de jour, comme de nuit. Quant aux recherches électroniques, elles ont fait appel au radar de bord Sperry 4016

fonctionnant dans la bande X et au radar Sperry 340. Les repérages ont été confiés au personnel de la GCC. Des matelots et des quartiers-maîtres ont agi comme vigies tandis que les officiers (surtout des surnuméraires) occupaient les postes radar.

De retour à sa base de Dartmouth le 1 er novembre, le navire y est demeuré jusqu'au 5, le temps d'installer un radar de bord Pathfinder ST de Raytheon utilisant des visuels à balayage ligne par ligne. Il a rejoint le site d'expérimentation le 6 novembre. Du 9 au 20 novembre, les recherches visuelles et électroniques ont repris et, deux nuits durant, les lunettes de vision nocturne fournies par la Garde côtière des États-Unis ont été utilisées. En ce qui trait aux repérages électroniques, ils ont été menés à l'aide du radar de bord standard Sperry et du radar Raytheon Pathfinder ST. Les expérimentations ont pris fin le 24 novembre 1987.

Enfin, à l'étape IV, il a été procédé à la réduction des données, à l'analyse et la compilation des résultats ainsi qu'à la rédaction du rapport final. Concernant la réduction des données, les chercheurs ont fait appel à des techniques semi-automatiques afin de reconstituer les trajectoires et de regrouper, dans des fichiers, les cibles repérées et confirmées et les cibles non repérées, selon le type de cible et de capteur, en plus des informations complémentaires nécessaires. Ils se sont servis de la méthode du maximum de vraisemblance, la même dont se sert la Garde côtière des États-Unis, aux fins d'analyse des résultats des recherches visuelles diurnes et nocturnes (radeaux éclairés) des recherches avec lunettes de vision nocturne et des recherches radar (transpondeurs radar), sauf celles des recherches radar de cibles passives. Pour ces dernières, on a effectué une analyse de régression linéaire visant à établir l'importance relative de toutes les variables indépendantes, à l'exception de la portée maximale de repérage. Une technique d'ajustement spline cubique a été utilisée en vue d'obtenir les courbes de probabilité de détection en fonction de la portée maximale de repérage et, à partir de celle-ci, la largeur des circuits de ratissage a pu être calculée. Le seuil de signification d'une variable indépendante: hauteur significative de houle, type de cible, visibilité, a été fixé à un niveau de confiance de 90 p. 100.

Le calcul de la largeur des circuits de ratissage a montré que celle-ci dépend de la portée maximale de repérage, de la visibilité, de la hauteur significative de houle et du type de cible (radeau 4 ou 6 places). Par comparaison avec les tableaux sur les largeurs des circuits de ratissage qu'utilise la Garde côtière canadienne, les largeurs tirées des expérimentations ont été, toutes choses étant égales, à peu près le double, voir le triple, des premières, et ce dans tous les cas de recherche. Ces résultats soulignent l'importance d'utiliser des navires stables et de forte taille pour les opérations de recherche et de sauvetage.

Les résultats des recherches visuelles nocturnes indiquent que la portée maximale de repérage est le seul paramètre significatif, la largeur du circuit de ratissage correspondante s'établissant à 2,2

milles marins (MM). Bien que fondés sur des données peu abondantes, les résultats présentent une faible dispersion et dégagent un niveau de confiance peu élevé, mais acceptable. Les paramètres de vitesse du vent et de hauteur significative de houle ont dégagé un seuil de signification juste au-dessous de 90 p. 100. Le seuil pour l'un ou l'autre de ces paramètres, ou les deux, aurait pu être plus élevé si la cueillette de données avait été plus riche. Jusqu'ici, aucune valeur de largeur de circuit n'avait été calculée à l'égard des radeaux de sauvetage équipés de feux de position. Cependant, des résultats portent à croire que les valeurs approximatives indiquées dans certains documents seraient trop élevées dans le cas de torches électriques et de lampes-éclairs fixées aux vestes de sauvetage.

Les résultats des recherches avec lunettes de vision nocturne ont montré, une fois de plus, que la portée maximale de repérage est le seul paramètre significatif et que, à l'instar des recherches visuelles nocturnes, les paramètres de vitesse du vent et de hauteur significative de houle dégagent un seuil de signification juste au-dessous de la limite. Quant à la largeur de circuit correspondante, elle a été calculée à 1,4 MM. Toutefois, eu égard au peu d'abondance des données et à la forte dispersion constatée, la limite de confiance correspondante est faible. Il faut remarquer cependant que pour bien fonctionner les lunettes de vision nocturne utilisées doivent bénéficier d'un peu de lumière venant du ciel alors que les recherches ont été faites sous un ciel complètement ennuagé.

Les recherches au radar, tout comme les précédentes, ont eu un seul paramètre significatif: la portée maximale de repérage. Les résultats de repérage avec un radar Sperry 4016 standard ont dégagé une valeur de largeur de circuit de 0,0 MM dans le cas de radeaux vides, et avec le Sperry 340 et le Raytheon Pathfinder de 0,4 et de 0,3 MM, respectivement. Dans le cas de radeaux équipés d'une lentille de Luneburg de 2 m^2 (surface équivalent à 4 personnes assises dans le radeau), placée à l'intérieur du radeau, le Sperry 4016 a dégagé une largeur de 0,6 MM, alors que, avec le même type de cibles, elle a été de 0,5 MM pour le Sperry 340. Dans le cas du réflecteur surmontant la tente, la largeur du circuit dégagée pour le Raytheon a été de 1,8 MM et celle pour le Sperry 4016 a été de 1,6 MM. Avec un transpondeur radar, elle a été de 8,8 et de 8,7 MM pour le Sperry 4016 et le Raytheon, respectivement. Des diagrammes polaires montrant la distribution des repérages selon la distance et l'azimut permettent de constater qu'il y a eu plus de repérages en direction avant qu'en direction arrière, et plus du côté tribord que bâbord. En outre, le radar Raytheon s'est ressenti de la présence du mât, comme en témoigne le manque total de repérages dans le 2^e quadrant tribord.

Toutes les recherches au radar, à l'exception de celles avec transpondeurs radar, ont nécessité, pour calculer la largeur du circuit de ratissage, des méthodes inhabituelles et presque toutes les courbes de probabilité de repérage en fonction de la portée maximale de repérage montrent une chute importante de cette probabilité à une portée maximale de repérage de, ou près de, zéro MM.

Quant aux résultats des recherches radar de cibles passives, ils ont tous souffert de l'occultation des cibles par les vagues. L'avantage d'un réflecteur haut placé ressort clairement du calcul des largeurs de circuit correspondant à un réflecteur surmontant la tente du radeau de sauvetage. Pour ce qui est des recherches radar avec transpondeurs, cette occultation est beaucoup moins pénalisante puisqu'il suffit d'un seul balayage réussi pour repérer la cible.

En observant les performances des radars les plus avancés, force est de constater que les techniques modernes de traitement des signaux visent davantage á débarrasser l'écran des signaux de fausses alarmes qu'à accroître la probabilité de détection des cibles à signature radar faible. L'aptitude du radar Raytheon Pathfinder ST à poursuivre ce type de cibles à l'intérieur de la zone de clutter de mer prouve clairement les améliorations que des techniques avancées de réduction du clutter permettent d'obtenir.

L'existence de zones de silence radar et de zones privilégiées sur lesquelles l'attention de l'opérateur se concentre au détriment des autres zones risque de fausser les résultats et de faire du navire concerné un cas particulier plutôt que général.

Les chercheurs estiment que la motivation de l'opérateur risque de se répercuter sur les résultats en débouchant sur des valeurs de largeur de circuit de ratissage quelque peu trop basses, comme ils l'ont constaté dans le cas des expérimentations dont il est rendu compte ici.

Voici d'ailleurs les recommandations qu'ils ont faites à ce propos:

1) Établir la largeur des circuits de ratissage en se fondant sur les valeurs du présent rapport pour les opérations de recherche de radeaux de sauvetage 4 ou 6 places, de couleur orange et jaune, respectivement, menées à bord d'un navire de la taille du NGCC Sir William Alexander et dans les conditions suivantes: visibilité 8 MM et plus, vitesse maximale du vent 40 noeuds, hauteur significative de houle jusqu'à 2,5 ou 3 m et précipitation nulle.

   Obtenir ces valeurs, pour tous les autres navires, des tableaux correspondants dans le Manuel national de recherche et sauvetage.

2) Mener une deuxième série de repérages visuels à bord du NGCC Sir William Alexander ou d'un navire jumeau dans des conditions permettant d'interpoler à la baisse les valeurs de largeur du circuit de ratissage, lorsque la visibilité est inférieure à 8 MM et que les précipitations sont intenses, et de déterminer la sensibilité de ces valeurs à la taille du radeau ainsi qu'à sa couleur.

3) Mener une autre série de repérages visuels, cette fois à bord d'un navire de même taille mais moins stable (le Alert, par exemple).

4) Mener des repérages visuels à bord d'un navire encore plus petit que les précédents, mais tout de même beaucoup plus gros que les navires exploités par la Garde côtière des États-Unis pour la recherche et le sauvetage (le Jackman, par exemple).

5) Lancer un programme de recherche conjoint - Garde côtière canadienne et Garde côtière des États-Unis - visant à développer et à affiner les modèles théoriques concernant les largeurs du circuit de ratissage pour des navires de classes et de tailles différentes, exploités dans des conditions variées et utilisant des cibles tout aussi variées.

6) Établir la largeur des circuits de ratissage à 2,2 MM lorsqu'il s'agit d'opérations de recherche nocturne de radeaux 4 et 6 places éclairés, menées à bord d'un navire de taille et de stabilité comparables à celles du Sir William Alexander et dans les conditions suivantes: visibilité supérieure à 10 MM, vitesse maximale du vent 40 noeuds, hauteur significative de houle 2,5 m maximum, précipitation nulle.

7) Ramener toutes les valeurs approximatives données dans le Manuel national de recherche et de sauvetage à 2,2 MM, dans le cas de torches électriques et de lampes-éclairs fixées aux vestes de sauvetage, jusqu'à la parution de valeurs plus précises tirees des expérimentations en cours.

8) Entreprendre de plus amples recherches nocturnes de radeaux de sauvetage éclairés.

9) Entamer, avec les fabricants de radeaux de sauvetage, des discussions portant sur les études qu'ils font sur diverses trousses d'éclairage: lentille-lampe-accumulateur, dans le but de les utiliser au cours des expérimentations à venir.

10) Mener de plus amples recherches utilisant les nouveaux modèles de lunettes de vision nocturne pour la recherche de cibles éclairées ou non. Par la suite, que le capitaine du navire concerné fasse l'appréciation des lunettes utilisées en fonction des conditions dans lesquelles les expérimentations se sont déroulées.

11) Établir la largeur des circuits de ratissage à 0,25 MM pour les opérations de recherche radar de radeaux 4 et 6 places, menées à bord d'un navire de taille et de configuration radar comparables à celles du Sir William Alexander et dans les conditions suivantes: vitesse maximale du vent 30 noeuds, hauteur significative de houle jusqu'à 2,5 ou 3 m, précipitation nulle, que les circuits de ratissage aient 0,25 MM de largeur.

12) Entreprendre de plus amples recherches radar-transpondeur radar.

13) Entamer, avec les fabricants de radeaux de sauvetage, des discussions portant sur la possibilité d'intégrer des réflecteurs

radar passifs et des transpondeurs dans la tente du radeau ou à une certaine hauteur au-dessus de celle-ci.

14) Limiter l'affectation des opérateurs à des tâches de recherche a un maximum d'une semaine, et ce pour toutes les experimentations à venir faisant appel aux techniques radar.

15) Lancer des appels de propositions, pour le compte de la Garde côtière canadienne et le CDT, concernant la mise au point, au Canada, d'un transpondeur destiné aux opérations de recherche et de sauvetage au radar qui ait pour le moins les caractéristiques et les performances de celui utilisé lors des expérimentations.

16) Concourir activement, de concert avec la Garde côtière canadienne et le CDT, aux travaux de R et D visant l'étude d'un système de traitement des signaux radar capable de s'adapter aux radars actuels et qui puisse en accroître l'aptitude à détecter des cibles à signature radar faible.

17) Prévoir pour les opérateurs des cycles de travail d'une heure entrecoupés par des periodes de repos d'au moins une heure, durant les opérations de recherche avec le radar de bord, menées par la Garde côtière.

18) Faire appel à des spécialistes en ergonomie et en psychophysique si jamais de plus amples recherches sont envisagées sur l'aspect ergonomique des opérations de recherche à l'aide du radar de bord.

19) Solliciter le concours d'un expert dans l'un ou l'autre de ces domaines, ou les deux, lors de la planification et la conduite des expérimentations de recherches visuelles et au radar visées par les présentes recommandations. Cet expert devrait également prendre part aux expérimentations in situ à titre d'observateur à l'affût de tout aspect particulier touchant l'élément humain.

20) Organiser un symposium ou un colloque international auquel participeraient les secteurs public et privé afin de les mettre au courant des travaux antérieurs et en cours dans le monde, d'établir un ordre de priorité en vue des recherches à venir et de créer un cadre international propice à l'élaboration de normes et de techniques acceptables par tous les membres pour l'exploitation des résultats jugés utiles.

21) Maintenir l'esprit de collaboration qui existe actuellement, grâce aux travaux entrepris conjointement avec la Garde côtière des États-Unis, en vue de prochaines opérations de recherche et de sauvetage.

22) Lancer une petite expérimentation de détection par radar aéroporté à l'occasion d'une future opération expérimentale de recherche et de repérage en mer à bord d'un navire. Le radar aéroporté visé serait le Litton 504(V)5 actuellement exploité à bord d'un aéronef

d'Atlantic Airways. Ce serait l'occasion d'évaluer ses performances et l'expérience ainsi acquise sera un précieux atout lors de la planification et de la conduite d'une expérimentation future faisant appel à un appareil de détection aéroporté.

23) Organiser des opérations expérimentales de grande envergure en mars ou avril 1989 au large des côtes de Terre-Neuve et faisant uniquement appel à des radars aéroportés: à antenne synthétique, à antenne latérale et de surveillance.

24) Lancer une expérimentation permettant de mettre les radiobalises de localisation de sinistres à l'épreuve.

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1. INTRODUCTION

To date, basic search planning by the Canadian Coast Guard (CCG) employs guidance derived from experiments carried out by the United States Coast Guard (USCG). These experiments have primarily involved conventional visual search experiments conducted off the mid-Atlantic coast of the United States. Sea states observed during the experiments were significantly lower and visibilities were frequently better than those typically encountered off the east coast of Canada, particularly during the spring and summer months. As a result, it is believed that the basis upon which sweep width is computed may not be entirely appropriate for searches in Canadian waters.

As an initial step to help remedy this situation, a pilot project was conducted in Placentia Bay in June, 1986, by NORDCO Limited (Dawe et al., 1986) under contract to the CCG. The purpose was to conduct a short visual and radar detection experiment prior to undertaking a major offshore experiment. The objectives were to:

1. provide familiarization with USCG methodology for data collection and analysis for deriving sweep widths;

2. augment the data base for determination of visual search sweep widths;

3. extend the USCG's methodology to electronic search techniques, specifically searches using standard marine X-band radar; and,

4. serve as a pilot project for a larger more complex offshore experiment.

The CCG, Newfoundland Region, provided the Search and Rescue (SAR) vessel, CCGS "Jackman", and other logistical support for the experiment, the first of its kind to be undertaken in Canadian waters.

This document constitutes the final report on the second ship based offshore SAR target detection experiment which took place in October and November, 1987, off Nova Scotia on the Canso Bank. The USCG participated in the project through the provision of advice, equipment, and observers on board the ship. The primary objectives of the experiment were to:

1. obtain visual sweep width data for Canadian SAR vessels in typical East Coast Canadian conditions;

2. add to the USCG data base on visual detection information for sea states 3 to 5;

3. determine sweep widths for standard ship's radars against unenhanced and radar reflector equipped life rafts; and,

4. determine the sweep width improvement that might be achieved using marine radars with sophisticated signal processing capability.

The targets of interest were four- and six-man canopied life rafts. Also, during the experiment visual night searches were undertaken for life rafts equipped with lights and for unilluminated life rafts using night vision goggles supplied by the USCG. Detection tests were also conducted utilizing targets equipped with SAR X-band radar transponders. The project was divided into the following four phases:

Phase I - Initial Preparatory Work
Phase II - Detailed Experiment Planning
Phase III - Field Experiment
Phase IV - Data Reduction and Analysis.

The results of Phase I have been reported separately (Dawe et al., 1987). The Phase II report is provided in Appendix A. The present report is primarily concerned with Phases III and IV.

2. OVERVIEW

2.1 Introduction

The project was divided into four phases to facilitate logical planning and to provide significant milestones through which progress could be clearly monitored and crucial decisions made regarding subsequent phases of the project. The activities of Phases I - IV are summarized in the following sections.

2.2 Phase I - Initial Preparatory Work

This phase was reported in detail in a separate publication (Dawe, et al., 1987). The objectives were to:

1. identify sources for forward-looking infrared (FLIR) systems and marine radar system equipped with sophisticated signal processing capability;

2. determine the degree and type of USCG participation in the experiment;

3. identify a suitable navigation system;

4. identify the ship, location, and time frame for the experiment; and,

5. assess the feasibility of using CCG radar simulators for conducting radar detection experiments and for investigating certain human factors that impact on the operation of a marine radar search.

The results of Phase I were as follows:

1. Because of the narrow field-of-view, low resolution, and potential problems due to sea spray and ship motion, it was considered not worthwhile, at this time, to test FLIR systems currently available on the market. A Sperry RASCAR and a Raytheon Pathfinder ST radar were selected as potential radar systems. Both systems have advanced processing units. The system to be utilized would depend on which one was available at the time of the field experiment.

2. The USCG agreed to supply a LORAN-C buoy and VHF receiver system and a number of radar reflectors. Tentative arrangements were also made to have at least one USCG representative on board the ship for a portion of the experiment.

3. A custom designed differential LORAN-C radionavigation system, which would meet accuracy and reliability requirements and satisfy the budgetary constraints, was recommended for use during the experiment.

4. The CCGS "Sir William Alexander" met the accommodation, availability, and other requirements for the experiment. The location designated for the field experiment was the Canso Bank area off Nova Scotia. The area has excellent LORAN-C coverage, minimal traffic, and is relatively shallow. A suggested start date for the experiment was September 15, 1987. This date was primarily dependent on the availability of the radar system and the ship.

5. The navigation/radar simulators at the CCG College in Sydney, Nova Scotia, and at the Transport Canada Training Institute (TCTI) in Cornwall, Ontario, were found to be inadequate for realistic radar target and clutter simulation and, therefore, unacceptable for simulated radar detection SAR experiments. The TCTI simulator was considered suitable for the investigation of certain human factors relating to electronic searches using marine radar.

In conclusion, all the objectives of Phase I were achieved.

2.3 Phase II - Detailed Experiment Planning

The primary objectives of Phase II were to:

1. investigate significant human factors relating to the operation of a marine radar in a search through the use of the TCTI navigation/radar simulator;

2. develop a detailed field experiment schedule;

3. develop a detailed experiment methodology; and,

4. develop the navigation system for the experiment.

The results of Phase II are summarized in the following paragraphs.

Both the experiment methodology and scheduling were addressed simultaneously. The methodology proposed for collecting data during the experiment was essentially the same as that used by the USCG in similar SAR experiments. In essence, a number of targets are moored in random locations distributed throughout the experiment area. A search pattern is developed and a simulated search is initiated. For the visual searches, lookouts are deployed as per a normal search operation. When a target is detected by a lookout the approximate range and bearing are to be reported to a monitor who, in turn, records the information along with the detection time and other ancillary data.

Extensive records of the environmental conditions are also to be maintained. Operators of the radar displays were to record their own detections. The radar operators would be required to work independently and visual cues were to be kept from them. Full details of the experiment plan are contained in the Phase II report, which is provided as Appendix A of this document.

The proposed navigation system is also described in detail in Appendix A. The hardware was assembled and the software developed accordingly. Section 3.4 provides a description of the final configuration of the system that was used during the experiment.

All the objectives of Phase II were accomplished. The only uncertainty was the navigation system, for which full testing and troubleshooting could not be completed until it was installed on a moving vessel.

An experiment to examine certain human factors relating to electronic searches using standard X-band marine radar systems was conducted as a separate part of Phase II of the project. A recommendation to examine these factors was made following the initial SAR detection experiment in Placentia Bay, Newfoundland (Dawe et al., 1986). The CCG technical advisor to the present project suggested that one of Transport Canada's marine navigation simulators may be suitable for conducting certain types of experiments related to SAR activities. Following an examination of the available facilities, an experiment to investigate certain interrelated human factors was designed and carried out using the simulator facility at TCTI in Cornwall, Ontario. The entire report on the simulator experiment is contained in Appendix B of this document. The specific objectives were to investigate the "look direction selectivity" of the average CCG radar operator and to investigate the time variability of target detection success in an effort to provide guidance regarding operator scheduling during search operations using marine radar. The major results of the simulator experiment are summarized in the following paragraphs.

The radar operators tended to see more targets on the starboard side and there was an indication of a tendency to look towards the forward half of the PPI display. The aft port quadrant had the least number of detections. The trend to look forward is consistent with previous ship experiment results. The tendency to the starboard side may be the result of training or the display design (clockwise turning scanner, and display refreshment).

More targets were detected at the edge of the major simulated sea clutter than at any other range. It is suggested that this might be the result of a tendency to look along edges or boundaries when searching.

The overall trend in the relationship between targets detected and number of opportunities indicates an inverse relationship. Although the explanations can only be speculative at this time, several were put

forth. One suggestion is that initially the operator is alert (more detections), gradually the trend is towards tedium and fatigue (less detections), and finally there is eagerness to make the last part of the experiment pass quickly (more detections). Another suggested explanation is that after the operator initially detected a high number of targets it was felt that there could not be very many more available and for some time afterward, the operators tended to concentrate less diligently. Towards the end of the experiment the operator, through a pattern recognition effect, begins to recognize more targets. A third explanation is that the operator has an upper level (which fluctuates somewhat) regarding the number of targets able to be tracked and detectable at any particular time.

The third trend suggests an overall drop in detection capability after one hour. The effect at the approach of the end of the experiment mentioned in the preceding paragraph is suggested as an explanation for the improvement toward the end of the 4 hour search.

It was concluded that look direction and range detection trends indicate the need for possible retraining of radar operators for SAR searches to ensure equal concentration is applied to all areas of the display or that investigations of different search patterns taking these factors into account be carried out. The inverse trend between percent detected and number of opportunities is suggested as not being significant in a real search. The time trend suggests the need to relieve operators after approximately one hour on watch; a coffee break is not sufficient.

It is doubtful that all of the trends noted could be verified adequately through a single ship experiment because of the low number of data points likely to be available. The use of experts in the fields of ergonomics and psychophysics might be required to fully understand the results observed in the simulator experiment.

2.4 Phase III - Field Experiment

A detailed chronology of events for the experiment is provided in Appendix C. An overview of the experiment is provided here.

The CCG, Maritime Region, tasked the CCGS "Sir William Alexander" to serve as the research SAR vessel for the project. Mobilization of the ship for the experiment was carried out at the CCG base in Dartmouth, N.S., from October 13 to 15, 1987. The ship initially departed Dartmouth on the evening of October 15, however, failure of one of three main engines forced a return to the CCG base for further inspection on Friday, October 16, 1987. Following the inspection, the ship departed the Dartmouth base on Friday evening, arriving in the experiment area (Figure 1) shortly after dawn on Saturday, October 17, 1987.

The field operations were conducted in two parts. In the first, two instrument and twenty target moorings were deployed initially, and

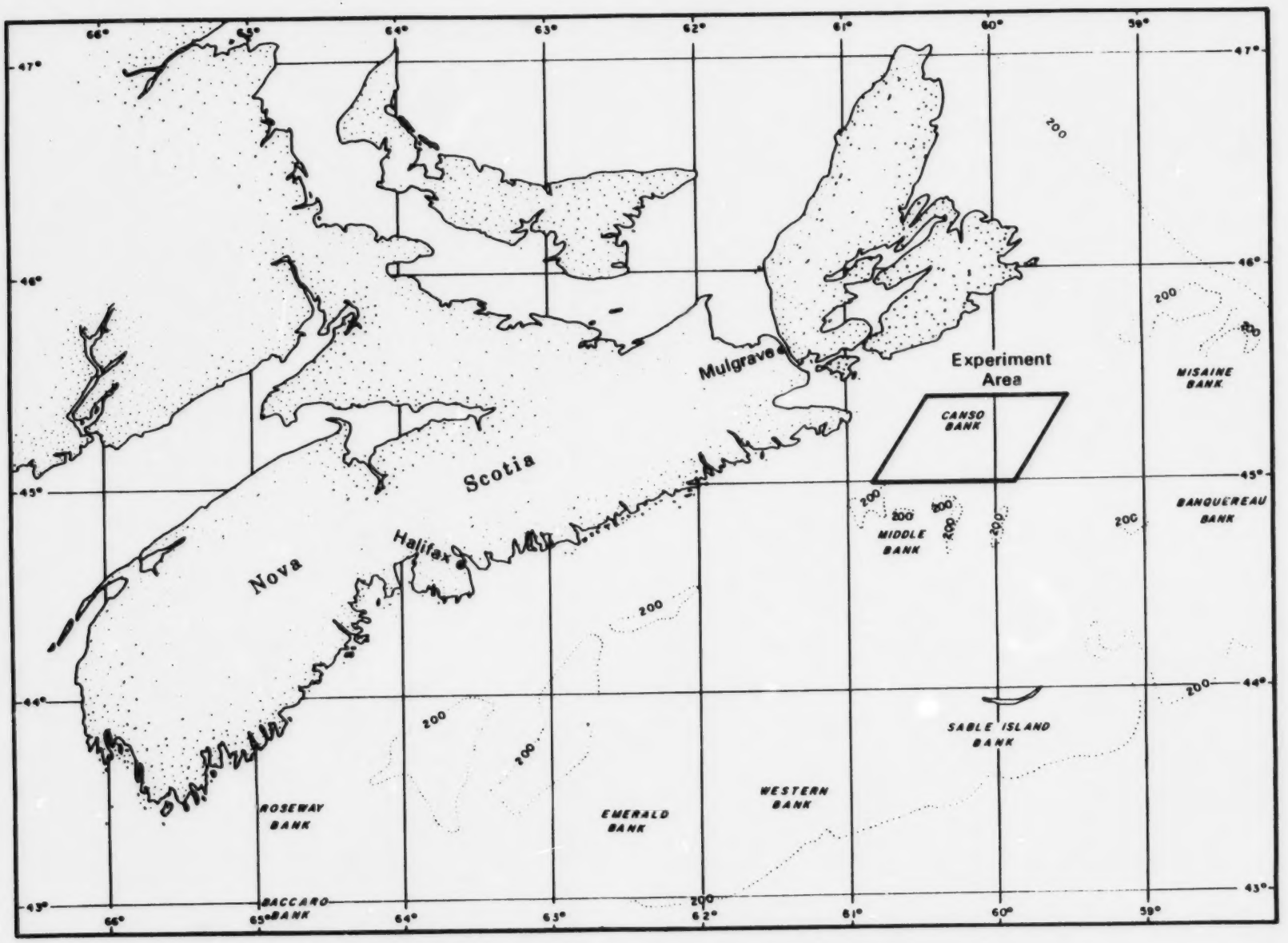

Figure 1 Location of Experiment

the navigation system hardware, software, and procedures were checked for proper function. The search targets, secured to the moorings, were either four- or six-man life rafts equipped with standard canopy lights. At any specific time approximately 10 life rafts were deployed. The radar reflectivity of some of the rafts was enhanced by suspending a 2 square metre (m^2) (radar cross section) Luneburg lens X-band radar reflector from the canopy tube. At times, an X-band transponder was deployed as a radar target.

Between October 19 and October 31, a number of radar detection tests were conducted and a total of 19 search patterns were run. Normally, parallel track search patterns were used. Visual searches were conducted during the day time as well as at night. Electronic searches, using a standard Sperry 4016 X-band marine radar and a Sperry 340 radar were also conducted. Target detections during the searches were made by CCG personnel. Seamen and leading seamen acted as visual lookouts while officers (primarily supernumerary personnel) undertook the radar watches. All life rafts were recovered on October 31, 1987 and the CCGS "Sir William Alexander" departed the Canso Bank for Dartmouth.

The ship arrived at the CCG base in Dartmouth on November 1 and remained there until late on November 5, 1987. During this period, a Raytheon Pathfinder ST marine radar (equipped with a raster display) was installed on the ship. The ship returned to the Canso Bank on November 6, 1987. High winds and seas delayed deployment of the life rafts, and during the intervening time, several radar detection tests were conducted in the more sheltered waters of Chedabucto Bay. From November 9 until November 20, 1987, twelve more visual and radar searches were conducted in the Canso Bank area. Night vision goggles, provided by the USCG, were used during two night searches. Radar searches were conducted using the ship's standard Sperry radar and the Raytheon Pathfinder ST unit. During this series of searches, the Luneburg lens type radar reflectors were mounted on spar buoys at canopy height.

Reallocation of the ship to other duties on November 20 forced an earlier end to the experiment than was originally planned. Commencement of instrument and mooring recovery operations was, however, delayed by high winds and seas until November 23. The ship departed Canso Bank at mid-day November 24 and arrived at the CCG base in Dartmouth the following morning. Demobilization was completed by November 27, 1987.

Table 1 shows a summary of the number and type of searches undertaken during the field experiment. A more detailed tabulation, providing summary information on the individual searches, is contained in Appendix D.

SEARCH TYPE	NUMBER	SEARCH TIME (h)	WIND SPEED (kt)	SIGNIFICANT WAVE HEIGHT (m)	PREVAILING VISIBILITY (nmi)
Visual Searches					
Daytime	21	116.0	Lgt. - 43	0.6 - 3.0	Good
Night	4	32.5	8 - 40	1.0 - 2.5	Good
Electronic Searches					
Night Vision Goggles	2	11.6	10 - 30	0.9 - 2.0	Good
Sperry 4016 Radar	26	142.2	Lgt. - 43	0.6 - 3.0	--
Sperry 340 Radar	11	64.2	8 - 43	0.9 - 3.0	--
Raytheon Pathfinder Radar	11	60.5	Lgt. - 37	0.6 - 2.5	--
Radars Against Transponders	4	20.4	6 - 30	0.9 - 2.0	--

Table 1 - Experiment Summary by Search Type

2.5 Phase IV - Data Reduction and Analysis

Following completion of the field work, the field data containing the detection reports and the environmental observations were assembled and reviewed, then, following an initial quality control check, entered into disk files on the NORDCO Limited DEC VAX/11-750 computer system. Following further quality control checks, the analysis of the detection data was carried out. Part 3 of the report contains a description of the relevant characteristics of the search vessel used during the experiment and, also, a summary of the instrumentation and equipment used. Part 4 provides details of the data reduction and analyses procedures that were carried out during the 1987/88 winter months. Results, a discussion, conclusions and recommendations are provided in the subsequent parts.

3. DESCRIPTION OF VESSEL AND EXPERIMENT HARDWARE

3.1 CCGS "Sir William Alexander"

The CCGS "Sir William Alexander", an 1100 class Coast Guard buoy tender/icebreaker, was christened at the CCG base Dartmouth in July 1987. The ship, which has an overall length of 85 metres (m), a beam of 16 m, and a displacement of 3728 tonnes, is somewhat larger than typical SAR vessels used by the CCG.

The ship was built with a very successful Flume Stabilization system which significantly damp the natural roll of the vessel. By all accounts, the CCGS "Sir William Alexander" was described as being an extremely stable ship in comparison to other Maritime region SAR vessels, particularly, the CCGS "Alert" and the CCGS "Mary Hichens".

The CCGS "Sir William Alexander" was made available by the Coast Guard for the full period of the experiment, but was, in addition, on SAR standby should the need arise. The officers and crew were, for the most part, normally assigned to the CCGS "Alert", which was undergoing a mid-life refit at the Marystown Shipyard in Newfoundland at the time. In addition to the normal ship's complement, and the NORDCO Limited scientific party, which varied between 5 and 10 individuals, the ship was also assigned three Supernumerary Officers and two officer cadets who participated directly in the radar detection experiments.

The ship was initially equipped with two Sperry radar systems: a conventional X-band marine radar (Sperry 4016) and a radar (Sperry 340) equipped with a Collision Avoidance System (CAS). In addition, a Raytheon Pathfinder ST radar system was installed on board the ship for the latter half of the experiment. Radar antenna heights ranged from 17.9 to 23.9 m.

Visual detection work was conducted from the enclosed bridge by seamen and leading seamen stationed on either side of the bridge. The height of eye was approximately 12.7 m above the sea surface. The stability and easy motion of the ship enabled lookouts to use binoculars during all of the searches. A large A-frame support for the ship's crane located just aft of the fo'c's'le restricted visibility from the bridge. The angle subtended by each frame leg from the normal lookout position on the port and starboard sides of the bridge was 3°. Otherwise, there were no other restrictions to vision caused by the superstructure through approximately 150° from the bow on either side of the ship.

3.2 Search Objects and Mooring Systems

3.2.1 Life Rafts and Moorings

Eleven four-man canopied life rafts and seven six-man canopied life rafts were used in the experiment. Normally about 10 rafts were deployed at any one time, 5 of each size. The rafts were stripped of all ancillary equipment other than the standard light mounted atop the canopy tube(s). The four-man rafts and one of the six-man rafts were international orange in colour. Six of the larger six-man life rafts were yellow. Of the total number of life rafts, only 4 were new; the remainder were rented from commercial suppliers or provided by the CCG or the Department of National Defence (DND).

Initially, an air supply system was provided in each raft in order to maintain air pressure in the floatation and canopy tubes for extended periods of time. The purpose was to reduce the frequency of raft servicing. Appendix A provides a detailed description of the system. The degree of success was highly variable. Where problems occurred, the primary difficulty was related to the connection of the air system to the inflation fittings on the raft. Since this problem could not be solved in the field, it was decided to remove the air supply systems and accept the necessity of more frequent servicing of the life rafts.

A description of the mooring arrangement used to moor the life rafts is given in Appendix A. The mooring gear was provided by the Coast Guard and prepared at the CCG Base, Dartmouth, NS. It consisted of two Norwegian net floats secured by polypropylene line to a concrete block. The life rafts were secured to the moorings with a polypropylene hollow braid bridle. The line was fixed between the inflation tubes. The method of attachment served very well and no chafe was observed at the raft or at the net buoys.

3.2.2 Lensref Radar Reflectors

Five Lensref omniazimuthal Luneburg lens type X-band radar reflectors were used to enhance the radar reflectivity of some of the life rafts. Manufactured by Tokyo Keiki Co. Ltd. of Japan, the Lensref reflectors had a radar cross section area of 2 m^2. A detailed description of the reflector is provided in Appendix E. This is approximately two times the radar cross section of a man standing upright (Skolnik, 1980) and for the purposes of this experiment, has been assumed to be approximately equal to the radar cross section of four men huddled inside a life raft. The Lensref reflectors, having a diameter of 20.3 centimetres (cm) and a mass of 2.5 kilograms (kg) were deployed in two distinct configurations during the experiment. Initially, the reflectors were mounted inside the life rafts, suspended from the canopy tubes at a height above the sea surface of approximately 0.7 m. During the second half of the experiment, the Lensref reflectors were mounted on spar buoys at a height of 1.1 m above the sea surface. This is approximately equal to the height of

the canopy tube of the four-man life rafts. The spar buoys were moored in a manner similar to the life rafts.

3.2.3 Melsweep Radar Transponder

During the experiment, several tests were conducted to provide some indication of the effectiveness of Mitsubishi Electric Corporation's X-band Melsweep Model H radar transponder developed for search and rescue purposes. The device consisted of a buoyant water tight housing containing an untuned crystal-video type receiver, a solid state varactor-tuned microwave FET oscillator transmitter, an omniazimuthal antenna, a light, and a alkali-manganese battery. The Model H transponder, with a diameter of 20 cm, a height of 59 cm and a mass of 2.8 kg, is activated by a mercury switch when turned upright. A brochure describing the unit is provided in Appendix F.

A transmission from the transponder produces a chain of 20 pulses on the Plan Position Indicator (PPI) display extending outward from its position. This symbolic display follows recommendations of the Inter-governmental Maritime Consultative Organization (IMCO) for radar transponder signal characteristics for search and rescue purposes (Inter-Government Maritime Consultative Organization, 1982). In very light sea conditions (significant wave height 0.3 to 0.5 m), with the unit floating on the sea surface and a radar antenna height of 15 m, the manufacturer's specifications indicate that the model H transponder signal has a maximum range of approximately 9.6 nautical miles (nmi). A Japanese report states that a life raft equipped with a Melsweep transponder was detectable by marine radar on a ship (antenna height 18 m) at about 10 nmi and by a search radar aboard a fixed-wing aircraft (altitudes 150 and 900 feet) at about 27 nmi (Japanese Ministry of Transport and Maritime Safety Agency, 1987). For a free-floating unit, the detection range was approximately 8 nmi from the ship.

The Melsweep radar transponder was deployed by either securing it with a painter to a moored life raft or attaching it directly to one of the life raft moorings.

3.3 Electronic Sensor Systems

3.3.1 Radar Systems

Three X-band marine radar systems were used onboard the CCGS "Sir William Alexander" during the offshore SAR experiment. Two of the systems were those that were installed on the ship at the time of commissioning. One radar, which is referred to as the standard Sperry radar, consisted of a Sperry MX-4016X PPI display, a 50 kW Sperry SeaThru transceiver, and a 2.74 m slotted array waveguide type antenna with horizontal or circular polarization. The antenna was mounted at 23.9 m above the design waterline. The other radar, referred to as the Collision Avoidance System or CAS radar, consisted of a Sperry 340X processor and display, a 50 kW Sperry SeaThru transceiver, and a 2.74 m slotted array waveguide type antenna. The antenna was located 20.6 m

above the design waterline. The CAS system contained full Automatic Radar Plotting Aid (ARPA) features.

A third radar system was installed aboard the ship in early November 1987 to examine whether its advanced signal processing facility would result in an improved detection capability for weak targets. This system was a Raytheon Pathfinder ST X-band marine radar with a raster display. The system consisted of a processing and display unit, a 25 kW Modulator Transmitter Receiver (MTR), and a 2.13 m antenna. Full ARPA features were also available with this system. The antenna was pedestal mounted at 17.9 m above the ship's design water line. The manufacturer's performance and main specifications of each of the radar systems are provided in Appendix G.

3.3.2 Night Vision Goggles

Two models of night vision goggles were made available by the USCG to permit a preliminary assessment of their effectiveness in conducting night searches. One of the units was the Litton Model M-912A/M-915A high performance night vision goggle unit. The other unit was a Litton Model M-927 aviator's night vision system. Copies of the manufacturers' brochures on the 2 units are provided in Appendix H. The units were used during two night searches and were operated by USCG observers attached to the project, and by CCG lookouts. One unit was provided with head straps, the second was mounted on an aviator's helmet; both systems were fully portable, being powered by self-contained battery packs. The night vision goggles employ image intensifier tube assemblies and were designed for use under moonlit or starlit conditions. The mass of the units is approximately 1 kg; in the case of the helmet mounted unit, the location of the battery pack at the back of the helmet counteracts the weight of binocular assembly in order to reduce fatigue to some extent.

3.4 Navigation System

3.4.1 System Design

Under Phase I of the project the development of a differential hyperbolic LORAN-C navigation system was recommended for use in the offshore SAR experiment. The proposed system was expected to meet a desired radial error accuracy (2drms - distance root mean square error utilizing 2 standard deviations) rating of 100 m or better. In Phase II, the system was developed and tested at NORDCO Limited. The on board component of the system consisted of a Compaq Portable II microcomputer interfaced to a shipboard LORAN-C receiver and a NORDCO produced Single Board Computer (SBC). The SBC was required to multiplex the input signals from the Magnavox MX 5102 Satellite Navigator and the VHF communications receiver. This was necessary since the disk operating system used on the microcomputer was capable of supporting only 2 serial communications ports. A more detailed description of the navigation system is provided in the Phase II report, included here as Appendix A. The function of the VHF receiver

was to receive LORAN-C time differences (TD's) data from a moored LORAN-C buoy located near the center of the experiment area on the Canso Bank. Average TD data from the three master-secondary transmitter pairs on the Canadian East Coast chain were transmitted once every 10 minutes. The purpose of the buoy data was to provide differential corrections for the random and systematic variations in the signal propagation speeds from each of the LORAN-C transmitters. The function of the satellite navigation receiver was to provide fixes from the US Navy Transit Doppler system from which additional secondary factors (ASF) would be computed. The intention was to develop an ASF time difference correction data base for the experiment area.

The shipboard LORAN-C TD data were to be logged to disk once every 24 seconds, the buoy data at 10 minute intervals, and the satellite fixes whenever they were received. Each record was time stamped with the GMT date and time. Software was written to monitor the serial port input, archive the raw data to disk, correct for cycle jumps, filter the TD data, calculate the ASF and delta ASF (differential) corrections, and compute the ship's position. The algorithm described by Shudde (1984) was followed to compute the latitude-longitude coordinates of the master-secondary pair crossings. The latitude-longitude output from a most probable position algorithm, which used weights based on the differences between the raw TD data and the filtered TD data, was archived to disk once every 24 seconds.

3.4.2 System Modifications and Operation

Very early in the experiment, an unacceptably large position error was obtained from the satellite navigation receiver. As a consequence, the Satellite Navigator was removed from the system. To compensate for this, the software was modified such that theoretically predicted ASF correction factors for each master-secondary pair were used. These data were provided by the Canadian Hydrographic Service with the caveat that their accuracy could not be guaranteed. However, this was of little consequence since it is relative accuracy rather than absolute accuracy that is of primary importance in an experiment of this nature. Nevertheless, the use of these data was expected to have resulted in an improvement in absolute position accuracy.

Two LORAN-C buoys were used during the experiment. Appendix A provides a detailed description of the taut mooring system that was employed to limit the horizontal excursion of the buoy. The buoy that was deployed during the first half of the experiment functioned correctly throughout the period. Upon recovery, the data stored in the unit's on board Random Access Memory (RAM) was downloaded to a microcomputer and archived on a floppy disk. The differential navigation system functioned reasonably well during this period (Searches 01 through 18) although occasionally, the system would lock-up due to data errors. Time did not permit a full examination of the problem in the field. Consequently, it was decided to use conventional hyperbolic LORAN-C TD data for real time positions during the second part of the experiment, and then to reprocess the data using

differential corrections from the buoy data following completion of the project. Unfortunately, the LORAN-C buoy data stored in RAM was lost when the unit was flooded following the failure of the antenna mounting arrangement. As a consequence, the ship's position for the second half of the experiment (Searches 19 through 32) were based on conventional hyperbolic LORAN-C position data only.

3.4.3 Navigational Accuracy

This discussion of navigational accuracy is based on an analysis of the position data from the LORAN-C buoy from October 18 to October 31. After correcting the data for cycle jumps, the latitude-longitude position was computed for each of the three TD pairs. Equal weighting was used to determine a most probable position. The distance from the observed positions to the mean position was then computed. Sixty-eight percent of the positions (one standard deviation) were within 52 m of the mean position and ninety-five percent (two standard deviations) were within 94 m of the mean position. The latter value represents the 2drms radial error of the LORAN-C hyperbolic position data and compares favourably with the desired 2drms accuracy limit of 100 m or less.

3.5 Environmental Monitoring Instrumentation

3.5.1 Meteorological Data

Meteorological and sea state observations were taken hourly during all visual and electronic search operations. As well, these observations were supplemented with additional observations whenever significant changes in conditions occurred between the GMT hourly readings. The following observations and derived data were recorded routinely:

- sky condition
- prevailing visibility
- weather (eg., rain, snow showers) and obscurations to vision (eg., fog)
- cloud types and amounts
- dry bulb temperature (° Celsius (°C))
- wet bulb temperature (°C)
- dew point temperature (°C)
- relative humidity (%)
- ship's heading (° True)
- ship's speed (knots)
- apparent wind direction (° relative)
- apparent wind speed (knots)
- true wind direction (° True)
- true wind speed (knots)
- barometric pressure (millibars (mb))
- mean sea level pressure (mb)
- sea surface temperature (°C)
- estimated sea wave height and period (metres (m), seconds (s))

- estimated swell direction, height and period (° True, m,s)
- degree of whitecapping.

Measured data were obtained using meteorological instrumentation available on board the ship. Temperatures were recorded from wet and dry bulb thermometers mounted inside the windward marine screen. The screens were mounted on the hand rails just abaft the bridge at a height of approximately 12 m above the sea surface. The anemometer was mounted near the top of the ship's mast at a height of approximately 28 m above the sea surface. No adjustment of the wind speed to a standard height has been made; consequently, the true wind speed that was logged and subsequently used in the data analysis represents the true wind speed at the anemometer height.

3.5.2 Real Time Wave Measuring System

A Datawell wave measuring buoy was deployed near the centre of the Canso Bank in 60 m of water during the initial set-up phase of the experiment. The wave buoy telemetered spectral wave data to a Diwar receiver installed on board the ship. An on board Compaq portable microcomputer, provided with the system, was used to process the data collected over a 27 minute period; the wave spectrum and certain wave parameters were output once every 30 minutes. The primary wave parameters of significant wave height and peak period of the spectrum were logged hourly along with the meteorological observations. The measured significant wave height was the value used in the detection data analysis. The wave buoy system functioned properly throughout the experiment; data were reliably received whenever the ship was within about 20 km of the wave measuring buoy.

3.5.3 Temperature/Humidity Sensor

Remote reading Weathermeasure Model 5121-B temperature/humidity sensors contained within self-aspirating radiation shields were mounted between 8.1 to 8.5 m just aft of the bridge on either side of the ship. The digital display was mounted on the bridge. The data, output from the windward sensor and logged hourly, in combination with the sea surface temperature were to be used to determine whether radar ducting conditions were present. Unfortunately, both humidity sensors failed very early in the experiment. As a substitute, the dry bulb temperature and relative humidity, determined from the ship's instrumentation, were used to examine the surface layer microwave propagation conditions.

4. ANALYSIS METHODOLOGY

4.1 Introduction

The analysis methodology that was employed followed, in general, USCG procedures for visual detection experiments and involved a multivariate regression technique to compute a relationship between various independent variables and the probability of search object detection. In addition to lateral range, defined as the minimum or least distance between the position of the search object and the observer's track (Koopman, 1980), relevant independent regressors include physical attributes of the search object (eg., size and colour), observer parameters (eg., height of eye and time on task), and environmental conditions (eg., significant wave height and prevailing visibility). Sweep width, the parameter used in search planning, is determined by integrating the probability of detection with respect to lateral range for particular values of the significant independent variables. Sweep width is interpreted as follows: the probability of detecting a search object beyond one half the sweep width or either side of the SAR vessel is equal to the probability of missing a target located less than one half the sweep width on either side of the search unit (Koopman, 1980).

4.2 General Methodology

Prior to performing the analysis, data reduction was carried out. In the past, a manual procedure was used to verify search object detection data and to compute lateral range data for the detection opportunities (Dawe et al., 1986). In this instance, because of the large volume of data, a semi-automated procedure was developed to assist in verifying target detections and for computing the lateral range or closest point of approach (CPA) of the detection opportunities. For each search an opportunity file was generated using the navigation data track file and the target data file. Two different algorithms were used in order to objectively identify the reported detections. Normally, both methods selected the correct target; where conflicts did occur, a subjective judgement was made. After manually scrutinizing the detection data, the successfully detected opportunities were flagged in the opportunities files. The data for individual searches were combined by search type forming the following files:

1. day light visual opportunity/detection file;
2. night visual opportunity/detection file for life rafts with lights;
3. night opportunity/detection file for life rafts without lights (night vision goggle searches):
4. Sperry 4016 radar opportunity/detection file;

5. Sperry 340 radar opportunity/detection file; and,
6. Raytheon Pathfinder ST radar opportunity/detection file.

The records also contained the observed environmental conditions at the time of detection or, in the case of missed opportunities, at the time of CPA.

4.3 Visual Detection Analysis

The maximum log likelihood model described by Cox (1970) was used to determine the probability of detection (P) as a function of a combination of a number of independent variables. A multivariate regression technique was used to determine the statistically significant parameters. The model uses the following equation:

$$P = \frac{1}{1 + e^{-\lambda}} \tag{1}$$

where, $\lambda = a_o + \sum_{i=1}^{n} a_i X_i$; and, (2)

a_o is a constant;

a_i are the coefficients of the given independent variable;

X_i are the values of the independent variable; and,

n is the number of variables.

The independent variables may be binary (eg., life rafts with or without canopies) or continuous (eg., wind speed). The variables are preselected and checked for their significance at the 90 percent confidence level in an interactive procedure. Those variables which do not contribute significantly to the variability of the predictand (λ) are rejected from the analysis. The model best fit is determined from only those variables which contribute significantly.

Having determined λ, P is determined for given values of the significant independent variables at all lateral ranges. Sweep width (SW) is then computed as:

$$SW = 2 \int_o^\infty P(x)dx \tag{3}$$

where x is the lateral range.

4.4 Radar Detection Analysis

The analysis methodology that was employed followed, in general, USCG procedures for visual detection experiments and involved a multivariate regression technique to compute a relationship between various independent variables and the probability of search object detection.

The detection records were sorted by lateral range, then binned using an iterative procedure to ensure that the equal size bins each contained approximately the same number of records and that no bins were empty. Finally, the percentage of targets detected in each bin was calculated.

For the passive radar targets a multivariate linear-regression technique was used to determine the statistically significant parameters. The variables were preselected and checked for their significance at the 90 percent confidence level in an interactive procedure. Those variables which did not contribute significantly were rejected from the analysis.

Plots of the percentage of radar targets detected versus lateral range suggested that the choice of an exponential model normally used for visual detection analysis (equation 1) was not appropriate for the radar detection data for all of the target types except the SAR transponder. Indeed, it is clear that the detection process for these passive radar targets is quite different from that of visual detection. The radar operator has to detect the target against a competing noise or clutter background. A number of echoes often must occur before the operator can identify a "blip" on the screen as a target. Quite often a "mental pattern recognition - like process" is required to identify the blip as a target. If the target enters the zone of significant sea clutter surrounding the ship in the near range, it quite probably is lost again, and the probability of detection curve as a function of range may actually decline in this area. Thus, intuitively, a monotonic exponential function is probably not applicable for computation of the probability of detection as a function of lateral range in this case. No other model has been proposed to date, and it was decided that a cubic spline curve fitting routine was the most appropriate to fit a curve to the percent detected data. The curve was extrapolated from the first bin back to zero lateral range. The sweep widths for various target types using the three radar systems were then computed by numerically integrating the area under the empirically derived curves.

Quite often the first detection of the transponder occurred when the first response was received. Had the response not had a series of radial delay echoes associated with it the target would no doubt have not been detected by the operator. This distinctive response enables easy detection in sea clutter and no reduction in the probability of detection in clutter. It was quite characteristic for the radar operator to recognize the target at the first detection although it may

have only been seen on one sweep. By the time the next single detection occurred (after as much as 5 to 10 full radar scanner sweeps later) the operator was able to obtain a range and bearing to the target. In this manner, with the transponder's distinctive response, the detection process is the same as that for visual detection. It was therefore considered appropriate to use the exponential curve and the standard visual analysis technique to determine the probability of detection and the resultant sweep width for the transponder.

5. RESULTS

5.1 Introduction

The following sections provide the probability of detection and sweep width results for the various individual sensor/target combinations. In all cases the multivariate regression analysis methods referred to in Section 4 were utilized.

Where sweep width is a function of lateral range only, data points are shown in the graphs of probability of detection versus lateral range. These data points are indicated as "X's" and represent the total number of detections divided by the total number of opportunities summed over all the searches for each lateral range bin.

5.2 Visual Search Results

5.2.1 Daylight Visual Detection

The factors tested for significance in the multivariate regression analysis were:

lateral range,
wind speed,
sea state (significant wave height),
visibility,
precipitation,
cloud cover, and,
target type (four- or six-man life raft).

The analysis showed that the optimum regression model in the maximum log likelihood sense included the independent variables of lateral range, visibility, significant wave height, and raft type. Table 2 shows a comparison of sweep widths obtained using this model with USCG sweep widths for various values and ranges of the regression parameters.

Table 3 contains a listing of the independent variables, their units, and the corresponding coefficients for daylight visual searches. Sweep width values may be computed for any combination of these variables by determining λ using equation (2), then the probability of detection from equation (1), and, finally, the sweep width by integrating equation (3).

5.2.2 Night Visual Searches For Life Rafts with Lights

A number of night visual searches were conducted for four- and six-man canopied life rafts with their exterior canopy lights

Sweep Width Source	Visibility (nmi)	Winds > 15 Knots Seas 2-3 Feet		Winds > 25 Knots Seas > 4 Feet	
		Raft Size		Raft Size	
		Four-Man	Six-Man	Four-Man	Six-Man
CCG (280 Foot Icebreaker/ Buoy Tender)	10	3.7	5.1	2.5	3.8
	15	5.4	7.0	4.1	5.5
USCG (90 Foot Work Boat)	10	2.0	2.4	1.0	1.2
	15	2.3	2.8	1.2	1.4

Note: Significant wave height for NORDCO Limited derived sweep width was set at 3 and 5 feet, respectively, for this comparison.

Table 2 - Comparison of Visual Sweep Widths (nmi) Derived from the Canso Bank Experiment with Sweep Widths Determined by the USCG

Symbol	Variable Name	Units	Coefficient
A_0	Constant	---	-0.8
A_1	Lateral range	Nautical miles	-1.2
A_2	Visibility	Nautical miles	0.2
A_3	Significant wave height	Feet	-0.4
A_4	Raft size	4: four-man, 6: six-man	0.5

Table 3 - Regression Coefficients for Sweep Width Computation for Daylight Visual Searches

illuminated. The results are based on only 4 searches. More searches were carried out, however, it was discovered that the canopy lights were not operating at full illumination. Those searches for which the illumination was low were subsequently eliminated from the analysis. The searches were conducted in the same manner as the daylight visual searches with the lookouts utilizing binoculars.

The factors tested for in the multivariate regresssion analysis were:

lateral range,
wind speed,
sea state (significant wave height),
visibility,
precipitation,
percent cloud cover, and,
target type (four- or six-man life raft).

The analysis showed that lateral range was the only significant factor. It is noted, however, that either wind speed or significant wave height would have been significant at slightly lower confidence levels (80 to 85%). Figure 2 shows the probability of detection versus lateral range curve. The derived sweep with is 2.2 nmi. Although this is only based on 4 searches the spread in the data is low and some confidence can be placed in the result.

5.3 Night Vision Goggle Search Results

Two searches were conducted using night vision goggles for unilluminated four- and six-man life rafts (canopy lights extinguished). The USCG personnel utilized the units during the first search (number 20), while in the second search (number 22) CCG lookouts alternated with the USCG personnel.

The factors tested for in the multivariate regression analysis were:

lateral range,
wind speed,
sea state (significant wave height),
visibility,
precipitation, and,
target type (four- or six-man life rafts).

There was 100% cloud cover present through both searches.

The analysis showed that lateral range was the only significant factor. Again, as with the night searches for lights, either wind speed or significant wave height would have been significant at a slightly lower confidence level. The sweep width was found to be 1.3 nmi. Figure 3 shows the resultant probability of detection versus lateral range curve. There is considerable spread in the data. It is

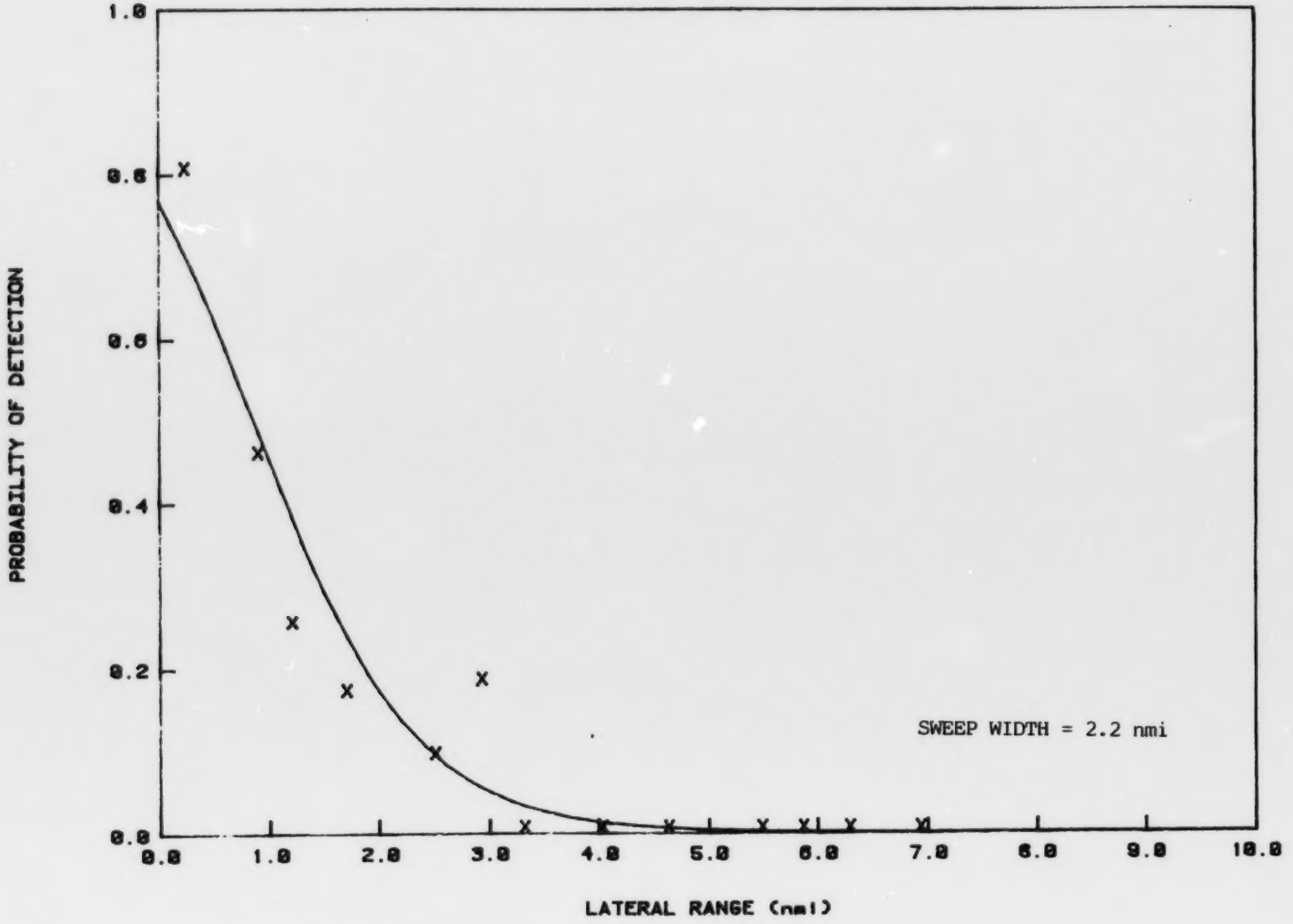

Figure 2 Night Visual Search for Lights Probability of Detection versus Lateral Range Relationship Derived from Experiment

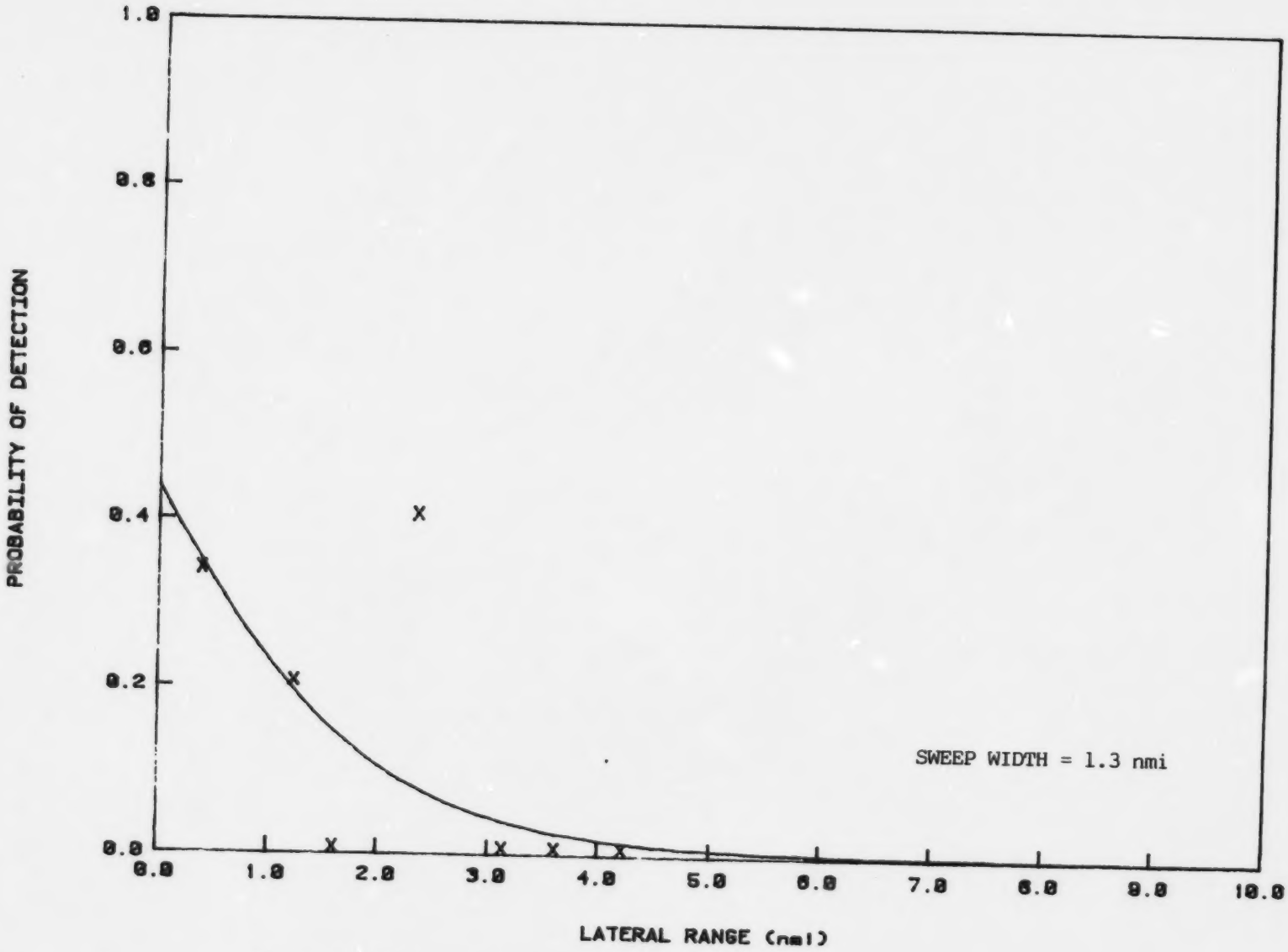

Figure 3 Night Vision Search for Unilluminated Targets Probability of Detection versus Lateral Range Relationship Derived from Experiment

noted that the night vision goggles were designed to operate with some moonlight or starlight available. The 100% cloud cover was not optimum for their operation. Newer models are being designed to operate under these conditions.

Reporting of objects with lights was discouraged because they were not the target of interest. However, 5 sightings of the LORAN-C buoy and the wave measuring buoy strobe lights were logged. Actual ranges of detection varied from 0.4 to 5.5 nmi. The average detection range was 2.4 nmi.

A number of operational difficulties were encountered in the use of the night vision goggle systems. Instrument lighting on the bridge had to be reduced to minimum intensity. All forward facing portholes had to be covered or the lights in the respective areas turned off. Water tight doors had to be closed. These lights illuminated the white bulkhead of the forepeak which in turn reflected light towards the bridge area. Indeed, without any light illumination, this white bulkhead was an annoyance. Operators had to be careful not to accidentally look at any lights inside the bridge as this had a blinding effect on the eyes. Some operator discomfort was noted as well. The maximum time period for which an operator could use the goggles was between 1 and 2 hours. The operators found the helmeted model to be heavy, causing excess neck fatigue.

5.4 Radar Search Results

The factors tested for each target type in the multivariate regression analysis for each were:

lateral range,
wind speed,
sea state (significant wave height), and,
the presence of ducting.

The analysis indicated that lateral range was the only significant factor. Table 4 summarizes the results, giving derived sweep widths for the various target types for each radar. With the exception of the life rafts, for which all three radars were tested, and in which the Sperry 4016 had a 0.0 nmi sweep width, each pair gave approximately the same sweep width. Figures 4 to 10 show the POD versus lateral range curves for the various radars and target types. As pointed out in Part 4, with the exception of the transponder, these are based on splined fits. The fitted curves, and even the data points in most cases, show a reduction in the near range.

Figures 11 and 12 are polar diagrams showing the distributions of the detections. The Sperry radar (both the 340 and the 4016) detections are shown separately from those of the Raytheon radar. The transponder results are not shown. In both figures there is a bias towards the starboard side and the forward section of the display. In total, more detections were made using the Raytheon than with either of the Sperry radars.

	SWEEP WIDTH (NMI)			
RADAR	LIFE RAFT	LIFE RAFT WITH REFLECTOR	REFLECTOR ON SPAR BUOY	TRANSPONDER
Sperry 4016 (standard)	0.00	0.6	1.6	8.8
Sperry 340	0.4	0.5	Not Tested	Not Tested
Raytheon	0.3	Not Tested	1.8	8.7

TABLE 4 - Summary of Marine Radar Sweep Widths Derived From Experiment

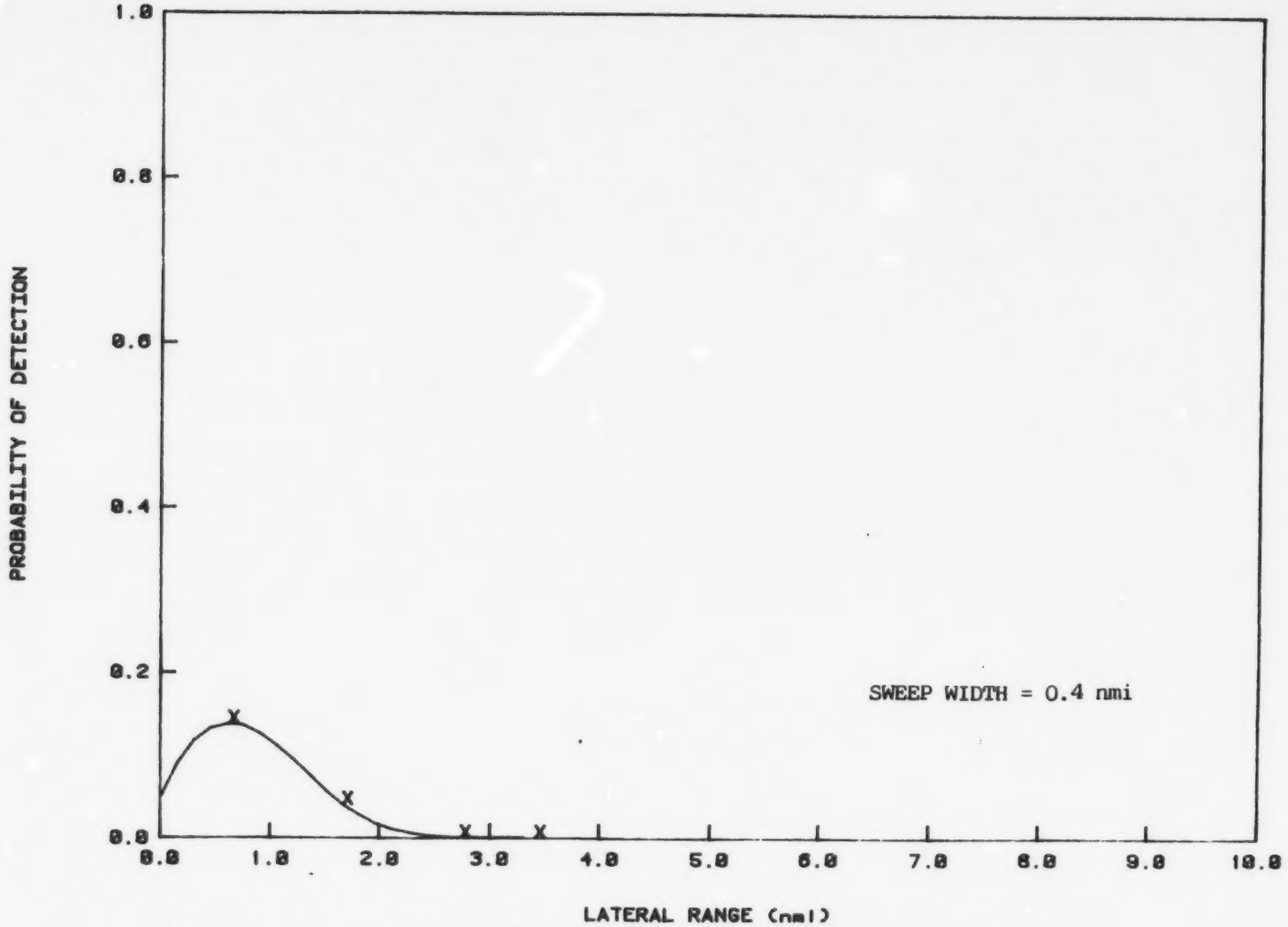

Figure 4 Derived Probability of Detection versus Lateral Range Relationship for the Sperry 340 Radar against four- and six-man Life Rafts

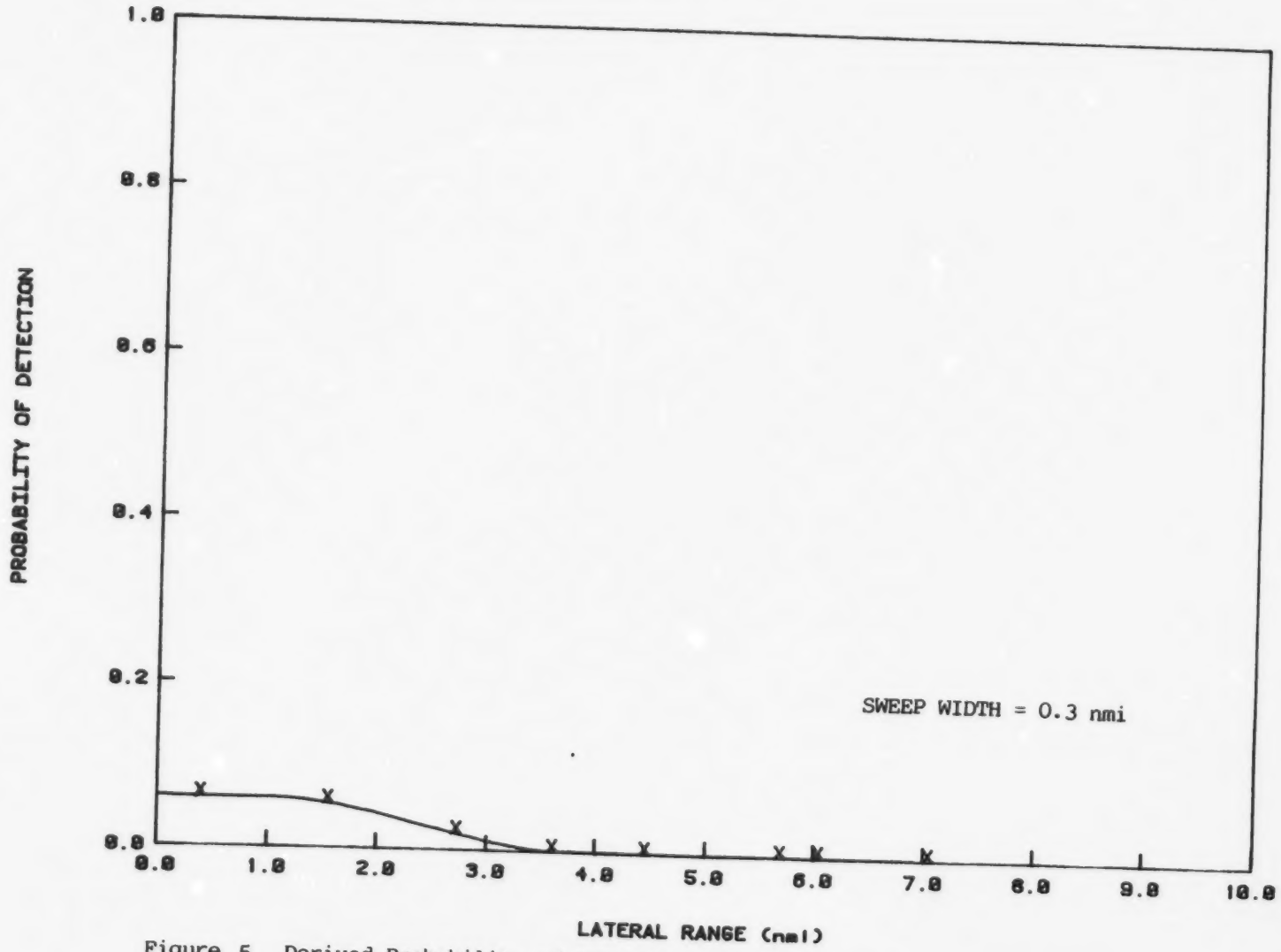

Figure 5 Derived Probability of Detection versus Lateral Range Relationship for the Raytheon Pathfinder ST Radar against four- and six man Life Rafts

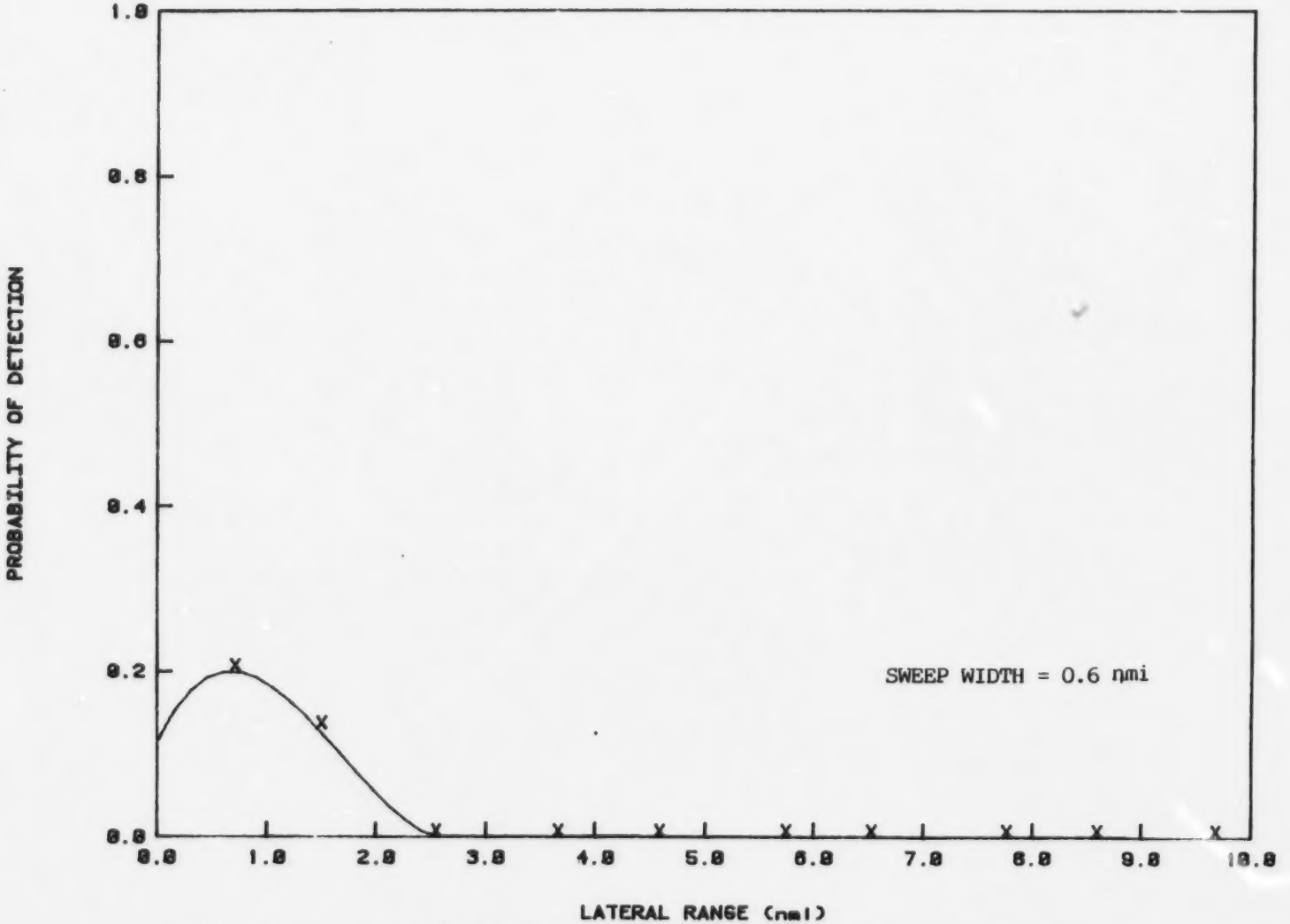

Figure 6 Derived Probability of Detection versus Lateral Range Relationship for the Sperry 4016 Radar against four- and six-man Life Rafts with $2m^2$ Reflectors Mounted Inside

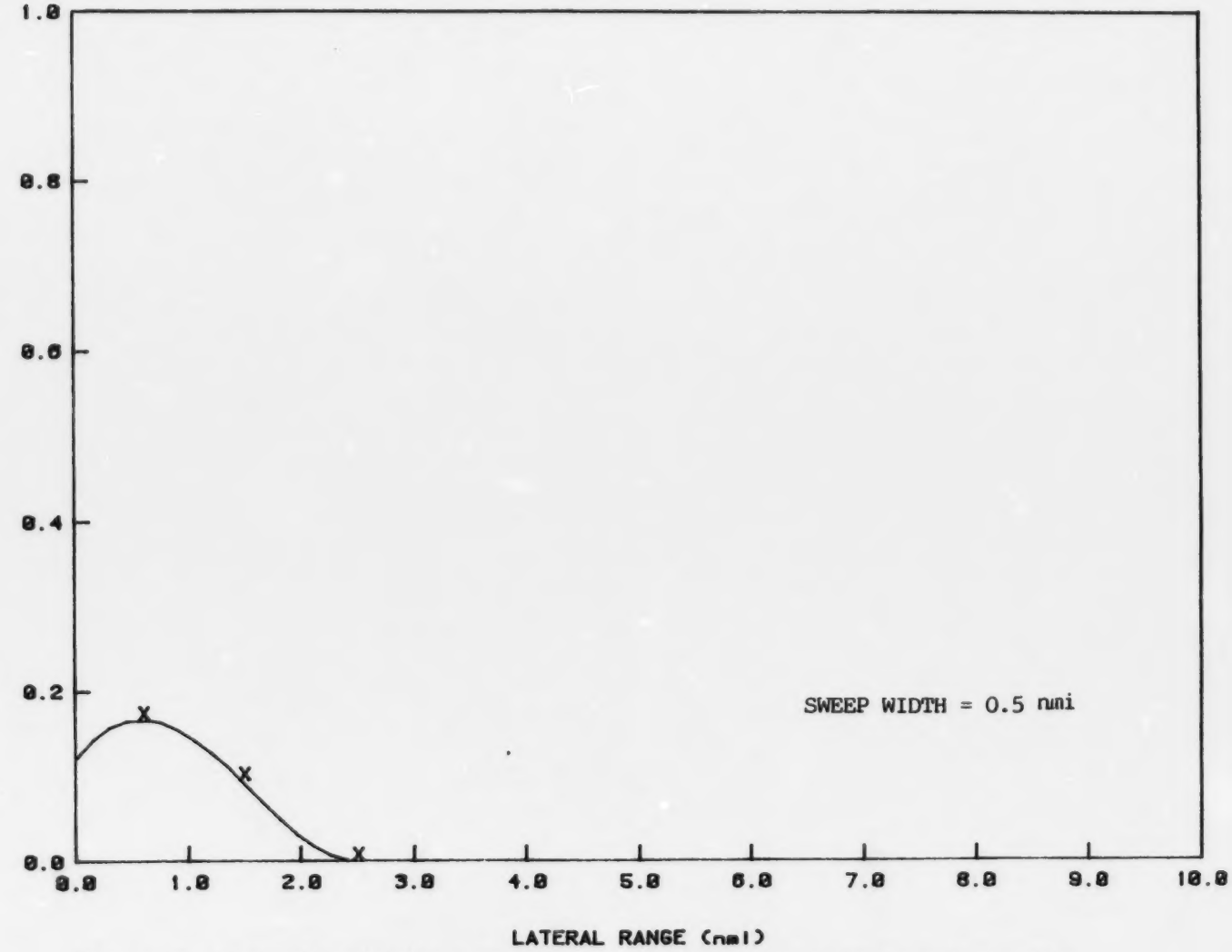

Figure 7 Derived Probability of Detection versus Lateral Range Relationship for the Sperry 340 Radar against four- and six-man Life Rafts with $2m^2$ Reflectors Mounted Inside

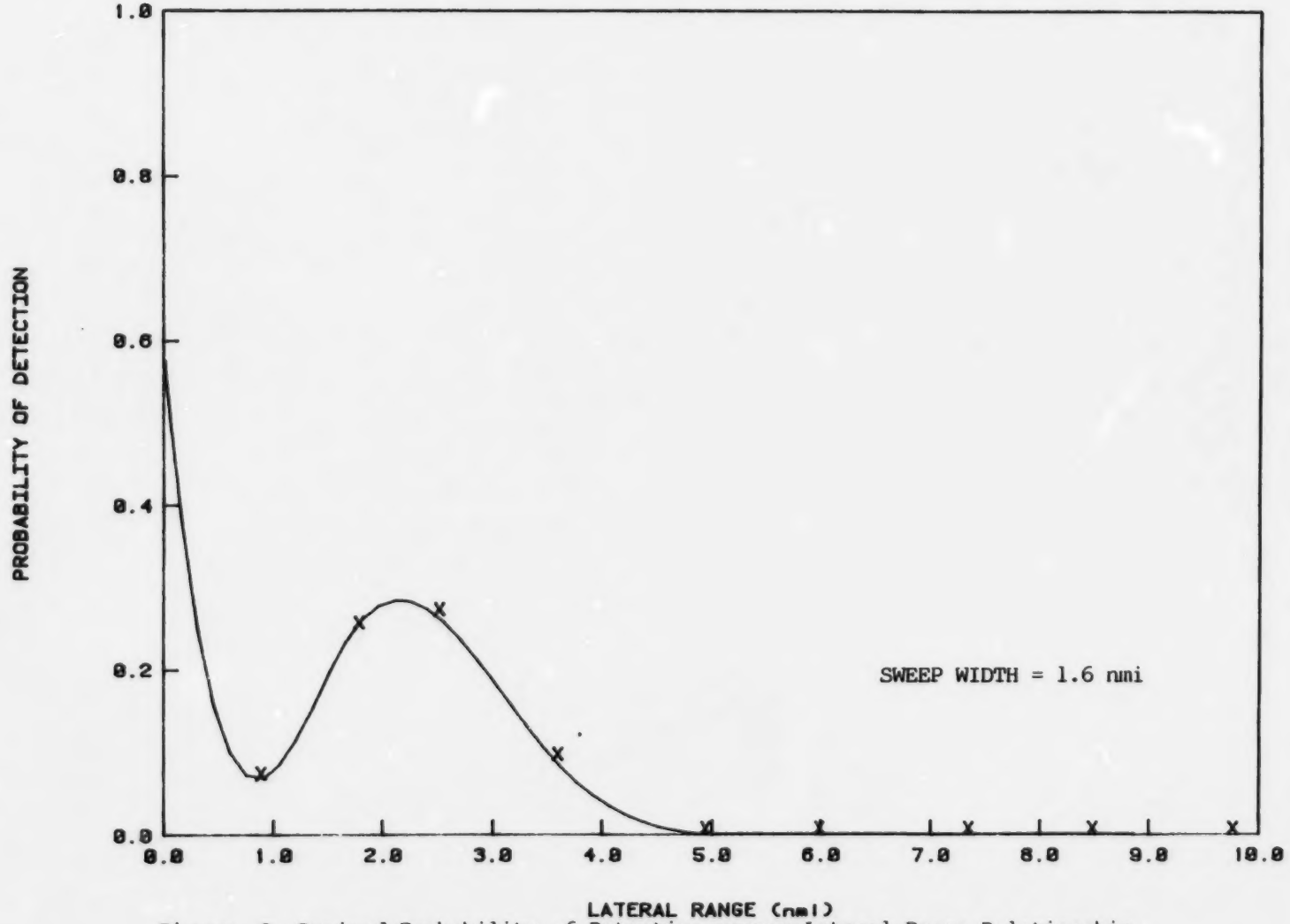

Figure 8 Derived Probability of Detection versus Lateral Range Relationship for the Sperry 4016 Radar against $2m^2$ Reflectors Mounted at four-man Life Raft Canopy Height

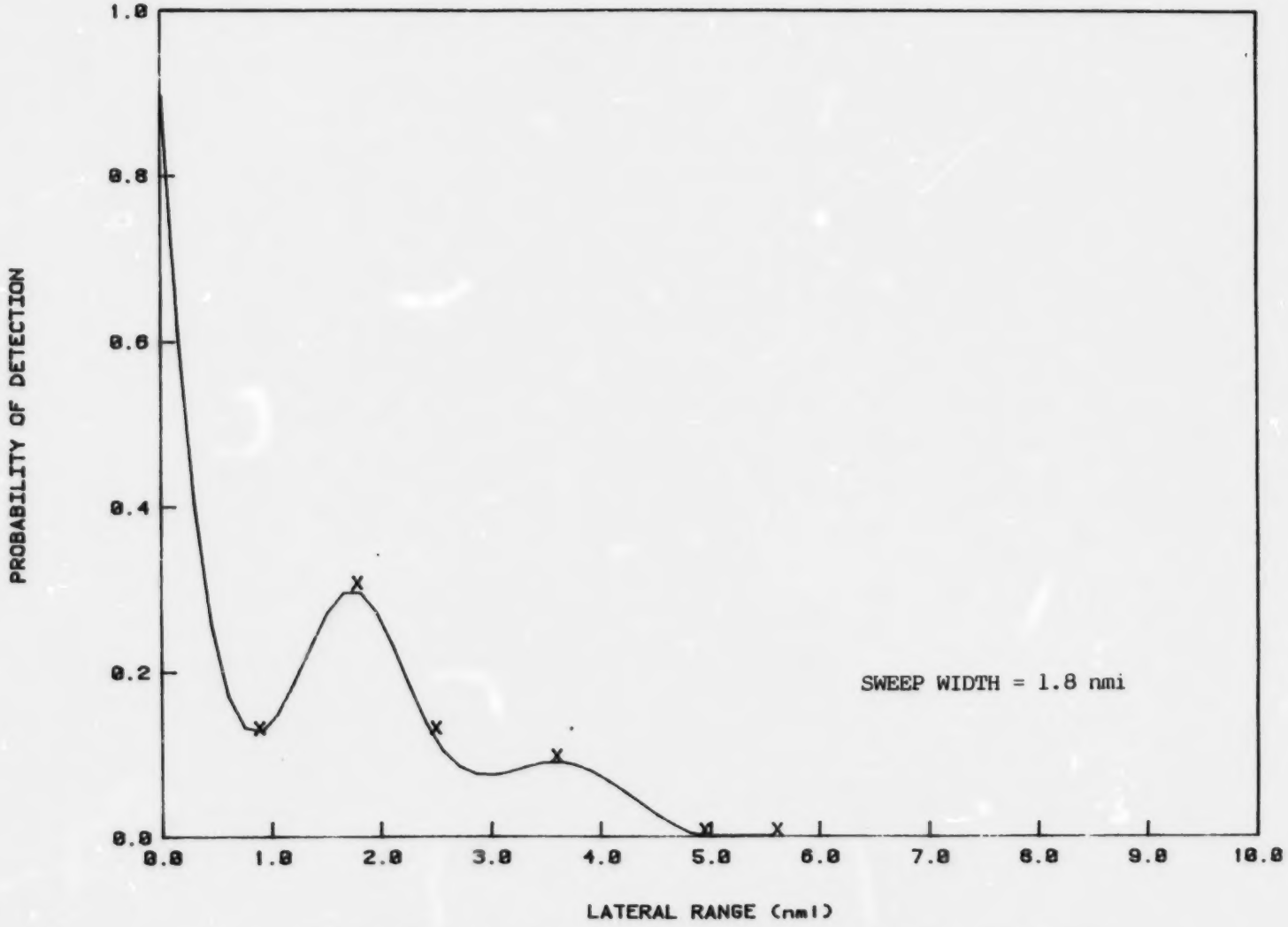

Figure 9 Derived Probability of Detection versus Lateral Range Relationship for the Raytheon Pathfinder ST Radar against $2m^2$ Reflectors Mounted at four-man Life Raft Canopy Height

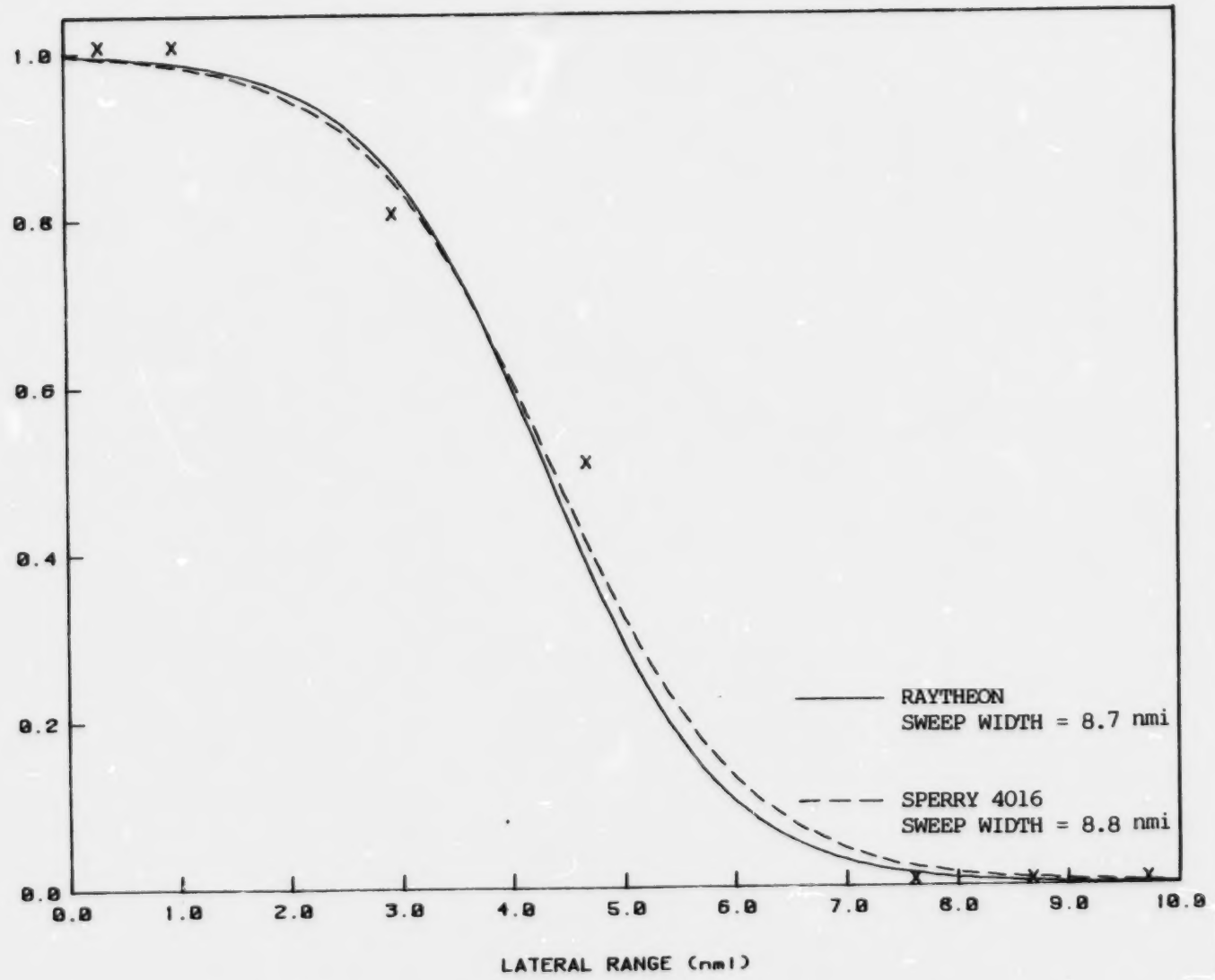

Figure 10 Derived Probability of Detection versus Lateral Range Relationship for the Sperry 4016 and Raytheon Pathfinder ST Radars against free-floating Melsweep Model H Radar Transponder

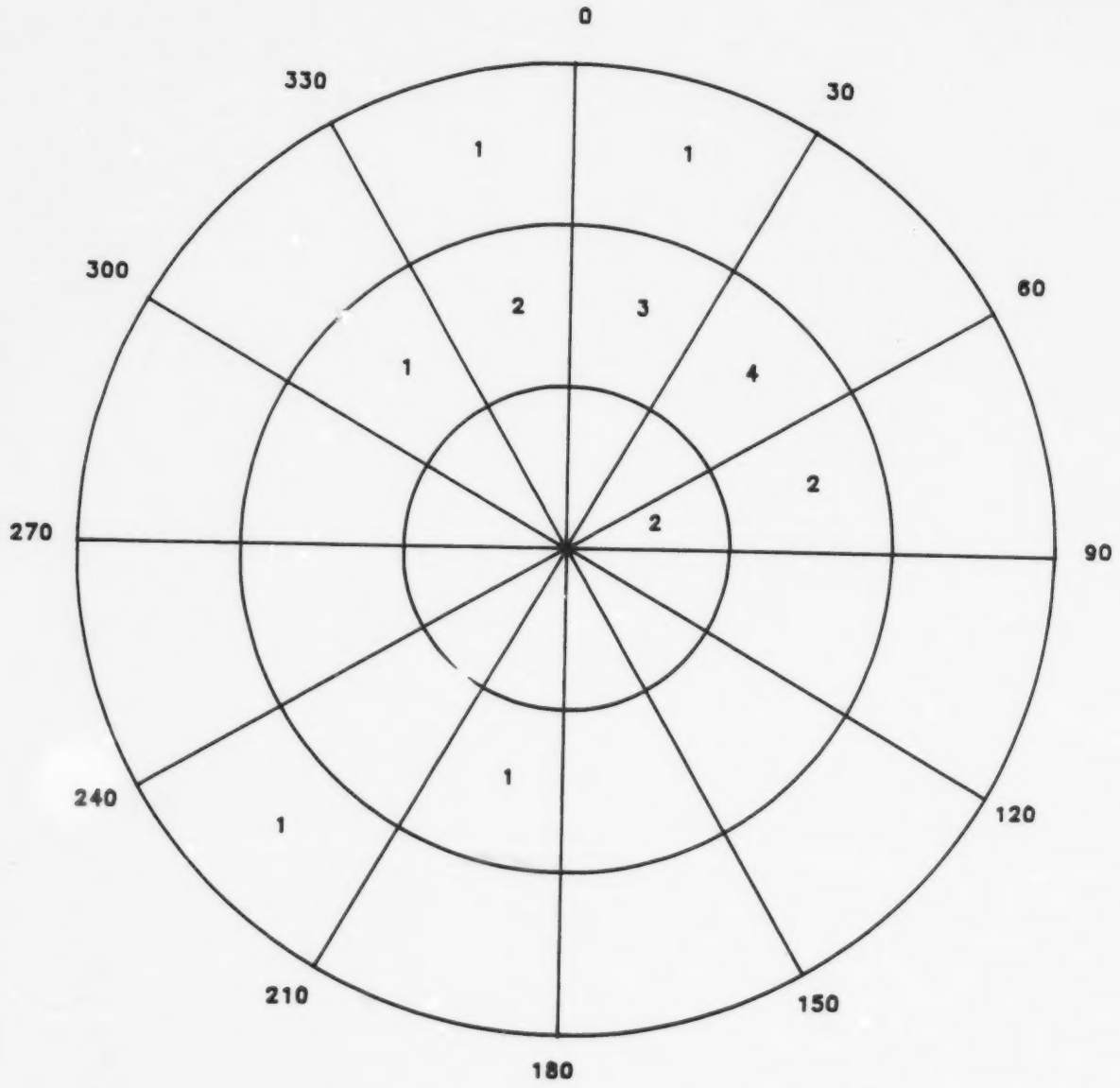

Figure 11 Relative Target Detection Positions for the Raytheon Pathfinder ST Radar System

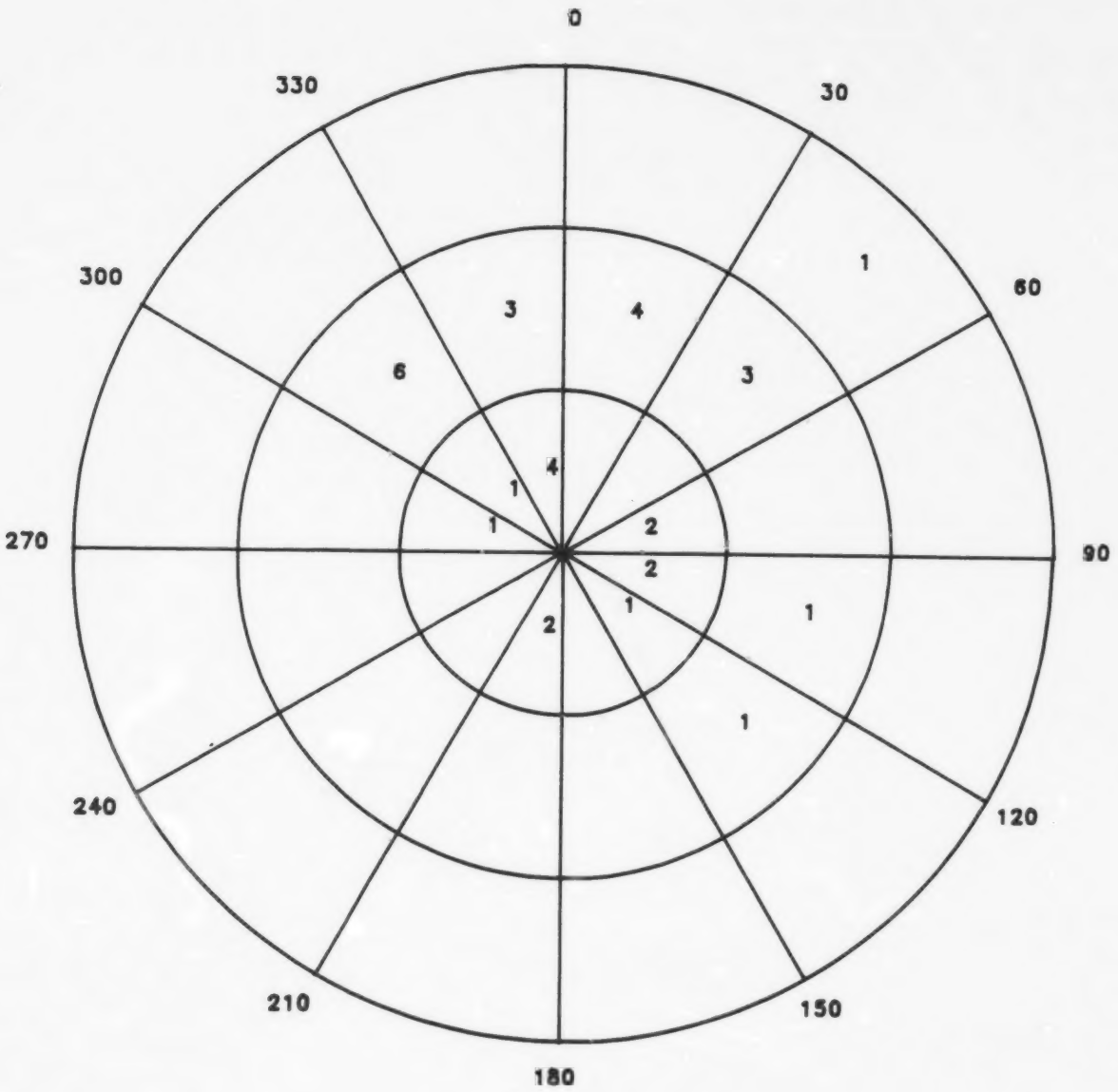

Figure 12 Relative Target Detection Positions for the Sperry 4016 and 340 Radar Systems

6. DISCUSSION

6.1 Visual Search Results

6.1.1 Daylight Visual Searches

Table 2 showed newly derived sweep width values developed by the USCG from 90 ft. work boats which are to be incorporated in the National Search and Rescue Manual (DND and CCG, 1985). Referring to Appendix D it can be seen that the environmental conditions for the present experiment are generally closer to the higher wind speed and sea state conditions listed in the table. The NORDCO Limited derived sweep widths under all conditions are approximately a factor of two greater than the values derived by the USCG for smaller vessels. A great deal of confidence may be placed in this result as the maximum log likelihood method used for the analysis shows a near perfect fit has been obtained. The major difference between the USCG experiments and the present experiment is the size and stability of the search platform. The CCG vessel was much larger than the USCG 90 foot work boats and was equipped with an efficient flume stabilization system. The results indicate that a more stable search platform greatly enhanced search detection performance.

An interesting result is the significance of the raft type parameter. The larger six-man life rafts were constructed of yellow fabric while the four-man life rafts were made using international orange material. Further work needs to be conducted to determine the significance of the size and colour of the search object.

6.1.2 Night Visual Searches For Life Rafts with Lights

No estimates of sweep width for night searches for life rafts equipped with standard lights have been reported previously. However, the National Search and Rescue Manual (DND and CCG, 1985) does provide estimated sweep widths (in darkness) for similar devices. These are compared with the NORDCO Limited derived result in Table 5. Table 6 shows results obtained in experiments by the USCG (Robe and Hover, 1986) for white life ring lights. The mean environmental conditions for the USCG were considerably better than those encountered in the present experiments, but the search units employed were much smaller. The sweep width values are seen to be equal for both USCG vessel sizes. Since very little data was available for the 90 ft. work boats, the values obtained for the 40 foot utility boats apply to the larger vessels as well.

An inspection of Tables 5 and 6 suggests that the National Search and Rescue Manual estimates may be high. The USCG results for life ring strobe lights are more comparable to those of the NORDCO derived

DETECTION AID	ESTIMATED SWEEP WIDTH (NMI)
Life Raft Canopy Light (From NORDCO Experiment)	2.2
Electric Floating Lantern	1.0*
Hand Flashlight	3.0*
Strobe LifeJacket Light	3.5*

* National Search and Rescue Manual (DND and CCG, 1985)

TABLE 5 - Comparison Between the NORDCO Limited Derived Sweep Width for Life Raft Canopy Lights and Estimates from the National Search and Rescue Manual for Similar Devices

SEARCH PLATFORM	TIME ON TASK (h)			
	1		3	
	WIND SPEED (kt)			
	6	15	6	15
41 Foot Utility Boat	3.9	2.6	2.1	1.1
82/95 Foot Work Boat	3.9	2.6	2.1	1.1

Mean environmental conditions

Cloud Cover (Tenths): 6

Significant Wave Height (m): 0.7

TABLE 6 - Sweep Width Values (nmi) for White Strobe Life Ring Lights Derived from USCG Experiments

results when the differing variables of ship size, environmental conditions, and light height are taken into account.

In referring to Table 2, another interesting comparison can be made. For the prevailing conditions encountered, the sweep width derived for this type of search is nearly double the daylight visual sweep width derived by the USCG for 90 ft. work boats (1.0 - 1.5 nmi).

6.2 Night Vision Goggle Searches For Life Rafts Without Lights

These searches were believed to be the first of their kind ever undertaken. The small data set and the spread in the data suggests that a relatively low level of confidence should be placed in the sweep width value obtained (1.3 nmi). Also, the USCG representatives on board the ship during the experiment noted that the particular night vision goggles used were designed to operate with some skylight available. The 100% cloud cover was not optimum for their use.

The Loran-C and wave measuring buoy light detection ranges suggests that these goggles may be very effective for illuminated targets (life rafts equipped with lights, etc.). The problems relating to their operation as discussed in Section 5.3 require further investigation.

6.3 Radar Searches

6.3.1 General Discussion

The sweep width results provided for all but the transponder should be viewed in light of the methodology used to derive the sweep width values. While, in principle, the method was the same, it did use an entirely new curve fitting routine. As explained in Section 4.4 this was felt to be justified because the nature of radar passive target detection is different from that of visual detection. The extrapolation of the curve to zero lateral range is likely to lead to some error in computation of sweep width. Further research will be required to develop an appropriate model for radar detection data.

It was obvious during the experiment that one of the major problems in detecting the radar targets was that they were physically obscured for a considerable portion of the time by large waves. This, then, is probably the primary reason for the reflector at canopy height giving the substantial improvement over targets having a reflectors suspended from the canopy tube.

An examination of the plots of probability of detection versus lateral range (Section 5.4) indicates that a substantially reduced probability of detection will occur near zero lateral range. This is probably due to the presence of sea clutter. The question arises as to whether the search track spacing should be less than the derived sweep width to provide overlap in the gap. Further investigations are necessary to resolve this issue.

All the radars had essentially the same primary system parameters. The Sperry radar systems had double the peak pulse power of the Raytheon unit, but the long waveguide runs are considered to have reduced the effective radiated power to that of the Raytheon system. The Raytheon did have a slightly lower antenna gain and a slightly wider beamwidth. The height differences between the 3 scanners were not considered significant.

Radar operator motivation was clearly a problem. Each operator was relieved after 1 hour in order to obtain the best performance as indicated by the simulator experiment (Appendix B). Some radar operators indicated a preference the Raytheon raster display while others preferred the standard PPI display. Occasionally, some operators became preoccupied with the Automatic Radar Plotting Aid (ARPA) functions on the Raytheon system. Others were reluctant to make any adjustments to the controls that are necessary to ensure optimum detection performance. The concentration level was clearly significantly lower than that observed in the Placentia Bay Experiment (Dawe et al., 1986).

6.3.2 Comparison Among Radars

Table 4 summarized the sweep widths derived. It is clear that for the weakest targets, the more sophisticated radars outperformed the standard marine radar, although even their sweep widths are small. For the remainder of the targets there was no significant difference among the Sperry 340, the Raytheon and the standard radars. This suggests that there are no significant differences between the performance of the more advanced radars and that of the standard radar except in the case of the weakest targets. Since the weakest targets were detected at the edge or within the zone of significant sea clutter, it would appear that radars having the more advanced processing capability had greatest benefit within that zone.

6.3.3 Effect of Passive Reflector Enhancement

Table 4 suggests that placing 2 m^2 passive radar reflectors within life rafts has little benefit over not using a reflector at all. However, placing the reflector at canopy height shows a substantial improvement. In fact, the derived sweep width is slightly greater than that of a visual sweep width for comparable conditions as reported by the USCG (Table 2).

6.3.4 Radar Transponder

Both the radars tested gave almost exactly the same performance against the transponders. The sweep width is 3 to 8 times greater than that for a visual search under comparable conditions as reported by the USCG (Table 2). Under most conditions, it is almost double the visual sweep widths derived from data gathered during the Canso Bank experiment.

The high performance of the radar transponder was due entirely to it being an active device. The detection process was discussed in Section 4.4, with the conclusion being that the process was the same as that of visual detection.

As noted earlier one of the major problems observed in detecting targets on the radar was that they were physically obscured by waves some percentage of the time. It is evident from the passive reflector results that had the transponder been placed at canopy height then a considerably greater sweep width would be expected.

6.3.5 Look Direction Selectivity

The simulator experiment (Appendix B) results indicated certain biases as to where the radar operators looked. The small number of detections available from the experiment makes it difficult to make direct comparisons. However, some general comments can be made. The Raytheon System was examined separately from the other two radars because of its very different raster display.

Figures 11 and 12 showed the relative positions of all passive radar target detections made with the Sperry radars and the Raytheon unit respectively. In both cases, more targets were detected in the forward half of the display than in the aft sector. They also suggest a bias toward the starboard side. This supports the conclusions of the simulator experiment (Appendix B) that radar operators tend to concentrate their attention on the forward and starboard sections of the radar display. For the Raytheon radar, a greater number of detections was made on the starboard side of the display than on the port half, all of them being in the first quadrant. A large shadow area in the second quardrant (from approximately 135° to 180°), created by the presence of the ship's mast, effectively reduced the opportunities for detection in that sector.

No major differences are evident between the detection distribution of the Raytheon raster display and the standard PPI displays. This suggests that display type does not affect operator look direction biases, an indication that training is the primary factor.

The small number of detections, the variable conditions, and the variety of targets makes it impossible to investigate the range effect.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Visual Daylight Searches

It is clear that the visual sweep widths for CCG vessels comparable in size and stability to the CCGS "Sir William Alexander" are considerably greater than those in the newly revised table now being incorporated into the National Search and Rescue Manual for four- and six-man life rafts for the range of conditions encountered. Greater sweep widths translate to more rapid area coverage in a search, and results in a higher probability of a successful rescue as well as substantial reduction in operational costs. As yet, the same cannot be said for ships of similar size but of significantly less stability (for example, the CCGS "Alert") or smaller SAR vessels, say of the size of the CCGS "Jackman". For ships of sizes comparable to that of the USCG SAR vessels typically used (41 to 95 ft.), it can only be assumed that the current SAR visual sweep width table is valid.

In discussions with CCG officers since the experiment it was noted that the visual searches provided training for CCGS lookouts. Indeed, a visual lookout, who located a black raft in a real SAR operation, after participating in the experiment, attributed his successful detection to search experience gained in this project. Thus, the visual detection experiment served as a training exercise as well as a research project.

A series of experiments is recommended, each of which has specific goals in mind. They will enable the CCG to undertake SAR operations with all their vessels utilizing an optimum set of sweep width values derived from Canadian vessels operating in Canadian conditions. Clearly, it is not feasible to undertake all the experiments within one year. A multiyear program is more realistic, with one to two experiments taking place each year. It is noted that the USCG recognizes the need for such an approach. Indeed, the revised sweep width tables now available could only have been developed from such a program. In the report on an earlier SAR experiment (Dawe et al., 1986), it was stated in the recommendations that:

> "...to make significant advances in the knowledge of sweep widths for visual and electronic searches from ships as they apply to typical Canadian conditions the CCG should initiate a multi-year program of experimentation."

The first priority of the CCG should be to develop an applicable set of visual sweep width tables for its own vessels so that SAR operations can be carried out in the most effective manner possible.

Specific recommendations are as follows:

1) For ships comparable to the CCGS "Sir William Alexander" searching for four-man orange canopy and six-man yellow life rafts in visibilities greater than 8 nmi, winds up to 40 knots, significant wave heights up to 2.5 to 3.0 m and no precipitation, sweep widths based on the results of this experiment should be used. All other vessels should continue to use the visual SAR sweep width tables provided in the National Search and Rescue Manual.

2) Another visual detection experiment utilizing the CCGS "Sir William Alexander" or a sister ship should be undertaken in conditions which will allow derivation of the reductions expected when operating in visibilities of less than 8 nmi and in significant precipitation. The dependency of life raft size and colour should be investigated as well.

3) A visual detection experiment should be undertaken utilizing a less stable vessel of the same size, the CCGS "Alert", for example. This will isolate whether the platform stability is a significant factor in sweep width determination and will add to the sweep width data base.

4) A visual detection experiment should also be undertaken using a smaller class of SAR vessel which is still significantly larger than a USCG SAR vessel (the CCGS "Jackman" for example). This should provide sufficient data to supply the CCG with sweep width information for this class of vessel.

5) A joint program between the USCG and the CCG should be initiated in order to develop and refine theoretical models for visual sweep widths for various types and sizes of vessels operating in a wide variety of conditions and looking for various targets. Such a model would considerably reduce the dependency on actual sweep width experiments and would enable the derivation of realistic and optimum sweep widths to cover almost any scenario. The USCG has already undertaken a considerable amount of work in this area.

7.2 Visual Night Searches for Lights

Visual night searches for life raft canopy lights have been shown to be effective, giving a sweep width of 2.2 nmi for the conditions experienced. Some caution should be used in regard to this figure because of the small data set. Based on this result, there is some evidence that the sweep width estimate of 3.5 nmi for the hand flashlight and the life jacket strobe light given in the National Search and Rescue Manual may be significantly high, at least for the conditions encountered during this experiment.

Non-standard batteries were used to illuminate the canopy lights and full illumination was available for only one night. After this the

lights were so dim as to render a night visual search ineffective. How well the normal battery pack would perform is unknown. Therefore, no conclusions can be made regarding the relationship between the length of time the light was activated and the effective sweep width.

In view of the results and the foregoing the following recommendations are made:

1) For ships comparable in size and stability to the CCGS "Sir William Alexander" searching for standard four- and six-man illuminated life rafts at night in visibilities greater than 10 nmi, winds up to 40 knots, significant wave heights up to 2.5 m and no precipitation, a sweep width of 2.2 nmi should be used.

2) The estimated sweep widths for hand flashlights and life jacket strobe lights given in the National Search and Rescue Manual should be reduced to at least 2.2 nmi until actual experimentally derived data is available to provide a more exact value.

3) More night search experiments for lights should take place in conjunction with the experiments recommended in Section 7.1 (recommendations 2, 3 and 4). The lights should include four- and six-man life raft canopy lights and strobe life jacket lights. Normal battery packs should be used.

4) Discussions should be held with life raft manufacturers regarding their plans for possible new lens/light/battery pack combinations so that these can be incorporated into the experiments.

7.3 Night Vision Goggle Searches

The results of the night vision goggle searches are rather inconclusive because of the small data set and the spread in the data. While some operational problems were identified, the significance of these in terms of operational utility is not clear. The light detection ranges and the ability of newer models to operate in 100% cloud cover provides some optimism for the future potential of these devices.

It is recommended that a more extensive experiment be conducted to test newer models against illuminated and unilluminated targets. This can be undertaken in conjunction with the experiments already recommended. It is also recommended that following the experiment the ship's captain provide an assessment of these devices in terms of the operational problems encountered.

7.4 Radar Searches

It is clear that for the range of conditions encountered the sweep width for empty four- and six-man life rafts with no radar enhancement is essentially zero. Life rafts with the 2 m^2 reflector mounted inside approximates a raft with 4 people inside. The sweep width is extremely small, and, taking into account the potential reduction near zero range, a value of around 0.25 nmi is probably a more realistic value. The effect of reflector height is clearly apparent when comparing sweep widths between reflectors mounted inside the life rafts and those mounted at canopy height. Obscuration by waves is partially overcome and an effective sweep width (taking into account the potential notch near zero lateral range) for the radar configurations employed is 1.6 to 1.8 nmi. The radar transponder is an excellent SAR radar target from the point of view of sweep width. For the particular radar installations and conditions the sweep width of 8.7 - 8.8 nmi is, on the average, double the visual sweep width for standard four-man life rafts. That the sweep width for these transponders is independent of darkness and low visibility makes the device even more attractive.

The performance of the various radars clearly shows that new processing schemes are directed more towards producing a clearer screen (reducing false alarms) than substantially improving weak target detection capability. The only area where a marginal improvement is indicated is in the case of the empty life raft. In this case the improvement is probably only the result of slightly better sea clutter reduction for the very near range.

The ability to track weak targets inside the clutter zone using the Raytheon radar clearly shows the improvement that might be achieved using more sophisticated clutter reduction schemes. The results of the Placentia Bay experiment (Dawe et al., 1986) showed the potential for improved detection outside the sea clutter zone when the radar pulse repetition frequency was effectively increased (scanner slowed to half speed) giving more successive "hits" on the target, resulting in significantly longer detection ranges. The obscuration by waves remains a significant problem for any radar. In view of the foregoing, there is clearly a requirement for radar systems specifically designed for weak target detection. Such radar systems will require substantially greater processing power than that possessed by any of the commercial marine radars now available. While significant improvements might be achieved by changing fundamental radar parameters (scanner speed, power, pulse scheme, receiver design, etc.), it is felt that the most cost effective approach at this time is to concentrate on signal processing.

There is some evidence that radar shadow areas created by the ship's own structure can have a detrimental effect on detection in certain directions. Also, there is evidence that suggests radar operators tend to concentrate at least on the forward sector and the starboard side. A shadow area will contribute to a notch in the probability of detection versus lateral range curve, a reduction in the

sweep width, and a sweep width unique to a given ship. The operator bias will result in the effective search area around the vessel being distorted. Removal of these effects to provide more uniform coverage requires moving radar scanners to more appropriate locations, where possible, and possible specialized radar operation training for SAR duties.

Radar operator motivation was a concern during the experiment and this may have resulted in the measured sweep width being biased somewhat low. Some of the operators were cadets and their inexperience may have contributed to a reduced sweep width.

In discussions with CCG personnel since the field experiment, it seems evident that there is more interest in the Emergency Position Indicator Radio Beacon (EPIRB), which is to become a mandatory device on all vessels greater in length than 20 m in 1989, than in pursuing more experiments with radar and, in particular, with the radar transponder. This is felt to be short sighted in one way and risky in another. First, the CCG is placin all its "eggs in one basket". Secondly, it is quite clear that radar technology, like most others is advancing extremely quickly, and the time is not far off when SAR radar transponders could become very cheap, more compact, and just as common as the life raft canopy light or the life jacket strobe light. Not all search objects will be equipped with EPIRB's just as not all will be equipped with transponders. Some will have both. By continuing to undertake search experiments now under typical Canadian conditions, the CCG will be well versed in the performance (sweep widths) of the transponder when it does come into regular use. This will be unlike the situation with the EPIRB for which there is currently little known regarding a ship's ability to locate the device using standard radio direction finding techniques under typical Canadian conditions, even though the provision of EPIRBs is to become mandatory.

The following recommendations regarding radar search are made as a result of the experiment.

1) If a decision is made to conduct a search for four- and six-man life rafts using marine radar, then for ships of similar size and having similar radar configurations to that of the CCGS "Sir William Alexander" a sweep width of about 0.25 nmi (derived value reduced to cover notch in curve) should be used in winds up to 30 knots, significant wave heights up to 2.5 to 3.0 m, and no precipitation.

2) More SAR radar transponder experiments should be undertaken during the visual experiments previously recommended. These will provide sweep width values for different radar configurations and permit determination of the effect of transponder height (canopy height versus free floating).

3) Discussions should be held with life raft manufacturers to determine possible techniques for effectively incorporating

passive radar reflectors into the life raft canopy (for example, collapsible metallized mesh corner reflectors inside the canopy support tube). The possible incorporation of a radar transponder should also be included in this investigation. Also, appropriate methods for deploying reflectors at a substantial height above the life raft (even in high winds) should be investigated.

4) For any future experiments involving radar searches, it is recommended that the radar operators be assigned to the experiment for a maximum of one week each. This will serve to avoid or reduce deterioration in interest in the experiment with time, and should provide a broad base of personnel, and, presumably, experience which should increase the general validity and applicability of the experiment results.

5) The CCG and TDC should initiate solicitations of interest for the development in Canada of a SAR radar transponder which would have, at a minimum, the same performance level as the unit tested during this experiment.

6) The CCG and TDC should actively support research and development activities directed toward the design of radar signal processing units capable of being interfaced to existing radars and specifically designed to significantly improve weak target detection capability.

7.5 Other Issues

7.5.1 Radar Simulator Experiments

The radar simulator experiment indicated a number of human factors that would be important in a real radar search operation. The tendency to look forward and to the starboard, as found from the simulator results, appear to have been supported by the results of the ship based experiment. The tendency to detect more targets at the edge of the sea clutter zone coincides with other observations regarding the tendency to search along edges or boundaries. These are both significant trends in terms of a search operation. Unfortunately due to the nature of the experiment, the latter trend could not be verified. The drop in performance after about one hour, as found in the simulator experiment, was sufficient to justify the decision that, during the ship experiment, radar operators were to be relieved after one hour on watch. Other anomalies that appeared in the simulator experiment result, specifically, the inverse relationship between detection performance and number of detection opportunities and the tendency towards improved performance in the 3 to 4 hour time period are probably not important in terms of a real search operation. Because of the comparatively low number of opportunities and detections normally associated with a ship experiment, and other variables, many of the trends indicated will probably be difficult to verify confidently in such an experiment.

Whether more research should be undertaken in this area is primarily dependent on how important the CCG views marine radar as a search tool. Certainly, if it is considered so, there is sufficient evidence to suggest further investigations are required in order to identify potential operator retraining requirements and/or to derive more realistic search patterns for radar. Such investigations should involve human factors expertise in the areas of ergonomics and psychophysics.

The following recommendations are made:

1) In order to ensure maximum detection performance during CCG marine radar search operations, radar operators should be relieved after one hour. They should not return to radar duty until after at least a one hour period off search.

2) If any further radar simulator experiments are to be undertaken to investigate human factors affecting marine radar search operations, expertise in the area of ergonomics and psychophysics should be utilized.

3) During the planning and conduct of the recommended visual and radar detection experiments, an expert in the area of ergonomics and/or psychophysics should be consulted. Such a person should also participate in the actual experiment to observe and record significant human factor effects.

7.5.2 International Considerations

The USCG interest and, indirectly, that of the International Maritime Organization (IMO), indicates that the results of this project are of relevance to the international community. Since the results are applicable to other areas having similar environmental conditions, the greatest benefit can be attained from this project by ensuring that the results are made readily available to others.

At the present time the USCG is the international leader in the area of search and rescue experimentation. Indeed, through consultations with the USCG throughout the project and their active participation in the research to date, the quality and international compatibility of most of the data set has been assured. Continued cooperation can only ensure the maximization of mutual benefits from future projects. By cooperating with the international community the possibility of costly duplication of work is minimized, the assurance that acceptable standards are met is maximized, and the compatibility of the data and results collected and compiled by others can be ensured.

As pointed out in Part 4 of this document, the curve fitting methodology utilized for the passive radar targets was not a standard technique. This has implications on the utility of the probability of

detection versus lateral range curves derived and, ultimately, the resulting sweep widths. This type of experiment and analysis is an almost entirely new area. The USCG is only now becoming involved in the area and no standard has yet been established. The decision to use the spline fitting technique was made after discussions with a USCG contractor who, in some recent work with radar detection data, decided to utilize a non-standard technique. Clearly, it is necessary to establish an internationally acceptable model in this area to ensure compatibility of the results.

Even the standard data analysis methodology employed for visual detection has uncertain areas where judgements have to be made. For example, the methodology dictates a best fit to the data based on the multivariate regression analysis. Often an independent variable such as wind speed might be found to be marginally significant, however, its inclusion reduces the statistical goodness-of-fit. In this case the analyst has to make a judgement as to whether to include the variable and the decision might have a substantial effect on the sweep width derived. It is clear that some standardization in this area is required as well.

In view of the foregoing the following recommendations are made:

1) An international symposium or workshop should be organized involving government representatives and industrial expertise. The goals of this should be to familiarize all participants with past and on-going work undertaken by various countries, to establish areas of priority as far as research work is concerned, and to establish a forum whereby internationally accepted standards and methodologies can be formulated. Such a meeting may have to be repeated on a periodic basis. A natural by-product of the work will be the minimization of duplication in research efforts.

2) The degree of cooperation that has now been established between the CCG and the USCG should be maintained and nurtured or any future SAR research.

7.5.3 Airborne Radars

Searching from a surface platform either visually or electronically clearly has its limitations from the point of view of the sweep width, due to the relatively short visual and radar horizons and the problem of obscuration of targets by waves. Sophisticated airborne radar technologies are now commercially available. These may provide vast superiority in detection capability, (sweep width) area coverage, and provide effective search capability 24 hours a day in environmental conditions that might render surface searches totally ineffective. The USCG have recognized the potential of these technologies and, indeed, have already conducted experiments that have provided some very positive results (Ketchen et al., 1984 and Osmer et al., 1981). Again, as with the surface experiments they have been

undertaken in predominantly much less severe conditions than those typically experienced in Canadian waters. The radars available include surveillance radar systems, side-looking airborne radars (SLAR), and synthetic aperture imaging radars. The surveillance radar is specifically designed for small target detection (eg., submarine periscopes).

The airborne radar systems now available and, in some cases, in operational use off the East Coast of Canada, are in some respects technically superior in performance to those employed by the USCG in their experiments. It seems unfortunate that this equipment is not being utilized in present day search operations. Indeed, the true performance of these systems in typical Canadian conditions is not even known.

It can be concluded then that there is a need to conduct search experiments with these systems and the following recommendations are made:

1) An airborne radar experiment should be undertaken coincident with the next ship based SAR experiment. The Litton 504(V)5 radar, now deployed on an Atlantic Airways aircraft, should be the radar tested. The experiment will supply some performance information, and the experience gained will be invaluable in the planning and conduct of a future airborne detection experiment.

2) A major airborne experiment should be planned for the March - April, 1989, time frame off the coast of Newfoundland. During this period, the Atmospheric Environment Services SLAR, the Litton 504(V)5 radar, a commercial synthetic aperture imaging radar, and an experimental synthetic aperture imaging radar (owned by Energy, Mines, and Resources) will all be operated in the same area. The radars will be tested in a project called the Labrador Ice Margin Experiment, 1989 (LIMEX '89). This provides a unique opportunity to undertake comparative performance tests of these radars for SAR applications.

3) The CCG should consider launching a series of airborne radar and visual experiments coincident with the ship based experiments recommended above.

7.5.4 EPIRB's

As noted in Section 7.3, the provisioning of EPIRB's is shortly to become mandatory on certain types of vessels. It was also noted that there is little or no knowledge available regarding the effectiveness of ship based radio direction finding techniques in locating these devices in Canadian offshore waters. Experiments necessary to test this would be totally different from the experiment reported on here and from those recommended above.

It is recommended that an experiment be undertaken to test EPIRB's. The experience gained would not only provide a measure of performance of these devices, but also provide a valuable training exercise for SAR personnel.

7.6 Summation

The information gained from the ship based SAR detection experiment conducted off Nova Scotia in 1987 represents a significant increase in knowledge regarding visual and electronic searches under Canadian offshore conditions. As a result, specific recommendations have been made regarding searches in Canadian waters. The major recommendations provide clear guidance for a series of three to four experiments designed to provide the CCG with realistic and complete sweep width information for Canadian SAR vessels operating in Canadian waters. Other recommendations will ensure international compatibility of the data and the minimization of research duplication. Recommendations regarding testing new technologies are made so that the CCG can take advantage of them in the shortest possible time frame. While the technologies and the experiments may be expensive, this must be weighed against the increased potential for the saving of human lives and the increased search effectiveness which should result from the experiments.

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APPENDIX A

PHASE II - DETAILED EXPERIMENT PLANNING

SEARCH AND RESCUE
DETECTION EXPERIMENT
PHASE II - DETAILED EXPERIMENT PLANNING

SEPTEMBER 1987

BY

B. DAWE
D. FINLAYSON
D. BRYANT

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1. INTRODUCTION

This document constitutes the experiment plan for a ship based search and rescue visual and marine radar detection project. The experiment will use a methodology developed by the United States Coast Guard (USCG) for deriving sweep width data. The experiment involves mooring a number of four-man life rafts as targets in a pre-arranged array and operating a Canadian Coast Guard (CCG) search and rescue (SAR) vessel in standard search patterns through the array while visual and radar detections are recorded. In this experiment, the ship designated for the work will be the CCGS "Sir William Alexander".

There are 4 main objectives for the experiment. One is to obtain visual sweep width data under typical Canadian sea conditions (sea states 3 and higher). Another is to obtain sweep width data for a standard marine radar. The third objective is to determine the sweep width improvement to be obtained by using a marine radar equipped with sophisticated signal processing capability. A fourth objective is to investigate the improvement to be obtained in enhancing the radar reflectivity of the life raft through the use of passive radar reflectors.

The experiment is to take place over the approximate period of October 15 to November 30, 1987. The location will be the Canso Bank area off Nova Scotia. A 24 hour operation is anticipated with interruptions every few days for crew rest, crew changes, and target and mooring maintenance.

The following sections provide a detailed schedule, describe the location, describe the navigation system to be used, provide details on other equipment to be used in the experiment, give manpower requirements, and provide the detailed experiment methodology.

7. SCHEDULING

The planned schedule is as follows:

October 13 - 15	- Equipment installation and testing, life raft checks, loading of all ancillary gear
October 15 (evening)	- Ship steams for experiment site - Navigation system checked out
October 16	- Ship arrives at centre of experiment area and deploys LORAN-C buoy and wave rider buoy, followed by deployment of target moorings
October 17	- Continued placement of target moorings
October 18	- Completion of target mooring placement - Placement of life rafts on mooring - Begin radar and visual search patterns
October 19 - 20	- Continuation of radar and visual searches
October 21 (morning)	- Ship departs for Mulgrave for ship crew change
October 21 (afternoon)	- Ship departs Mulgrave for experiment site - Search initiated immediately upon arrival in experiment area
October 22	- Radar and visual searches continue
October 23	- Targets checked and refurbished as necessary
October 24 - 27	- Radar and visu l searches re-initiated
October 28 - 30	- Targets and moorings moved to new locations
Oct 30 (evening) - Nov 1 (morning)	- Searches are re-initiated
November 1	- Targets are recovered from moorings - Ship departs for Mulgrave
November 2 - 4	- Commanding Officer and Chief Engineer change - Raytheon radar system installed

	- Crew training on radar system initiated - NORDCO crew change - Raytheon representative joins ship
November 4 (evening)	- Ship departs for experiment site
November 5	- Targets placed on moorings
November 5 (evening)	- Searches re-initiated
November 6 - 8	- Searches continue
November 9	- Target and mooring maintenance - LORAN-C buoy batteries changed and/or replaced
November 10	- Searches re-initiated
November 11 - 13	- Searches continue
November 14 - 15	- Targets and moorings are moved to new locations
November 15 (evening)	- Searches re-initiated
November 17 (morning)	- Ship departs to Mulgrave for crew change
	Decision on continuing experiment
November 18 (afternoon)	- Ship departs for experiment site
November 18 (evening)	- Ship arrives on site and searches re-initiated
November 18 - 21	- Searches continue
November 22 - 23	- Target and mooring maintenance - Targets repositioned if necessary
November 23 (evening) - 26	- Searches re-initiated
November 27 - 30	- All target moorings retrieved - Wave rider buoy and LORAN-C buoy retrieval
November 30 (evening)	- Ship departs for Halifax
December 1 - 2	- Demobilization in Halifax

This schedule is subject to considerable change due to weather, equipment problems, or the ship being called out on a search and rescue mission. It is therefore meant only to be a guide. The LORAN-C buoy

may require maintenance on more than one occasion. Although the life rafts will be equipped with regulators and high pressure cylinders to ensure they are kept fully inflated, maintenance may be required more frequently. Decisions on removal of the life rafts temporarily will depend on forecast weather conditions, especially if the ship is departing the area for port. Relocation of the target moorings is required to avoid data biases due to the CCG observers "learning" the location of the targets.

On or about November 18, a decision will be made on continuing the experiment. This decision will be based on the amount of data collected, equipment difficulties encountered or expected to be encountered, and overall experiment progress.

3. EXPERIMENT LOCATION

The experiment will take place on the Canso Bank of Nova Scotia as shown in Figure 1. It was selected for the following reasons:

1. It is within an area of operation of the vessel (CCGS "Sir William Alexander") to be used in the experiment.

2. It is an area in which there are expected to be a minimal number of SAR incidents during the period of the experiment.

3. The area is an exposed offshore area where sea states of 3 to 5 can be expected.

4. It is close to the CCG base at Mulgrave, N.S.

5. The water depths will minimize mooring costs and operating difficulties.

6. The area is not a high traffic zone and this minimizes the possibility of interference.

7. The area has excellent LORAN-C coverage.

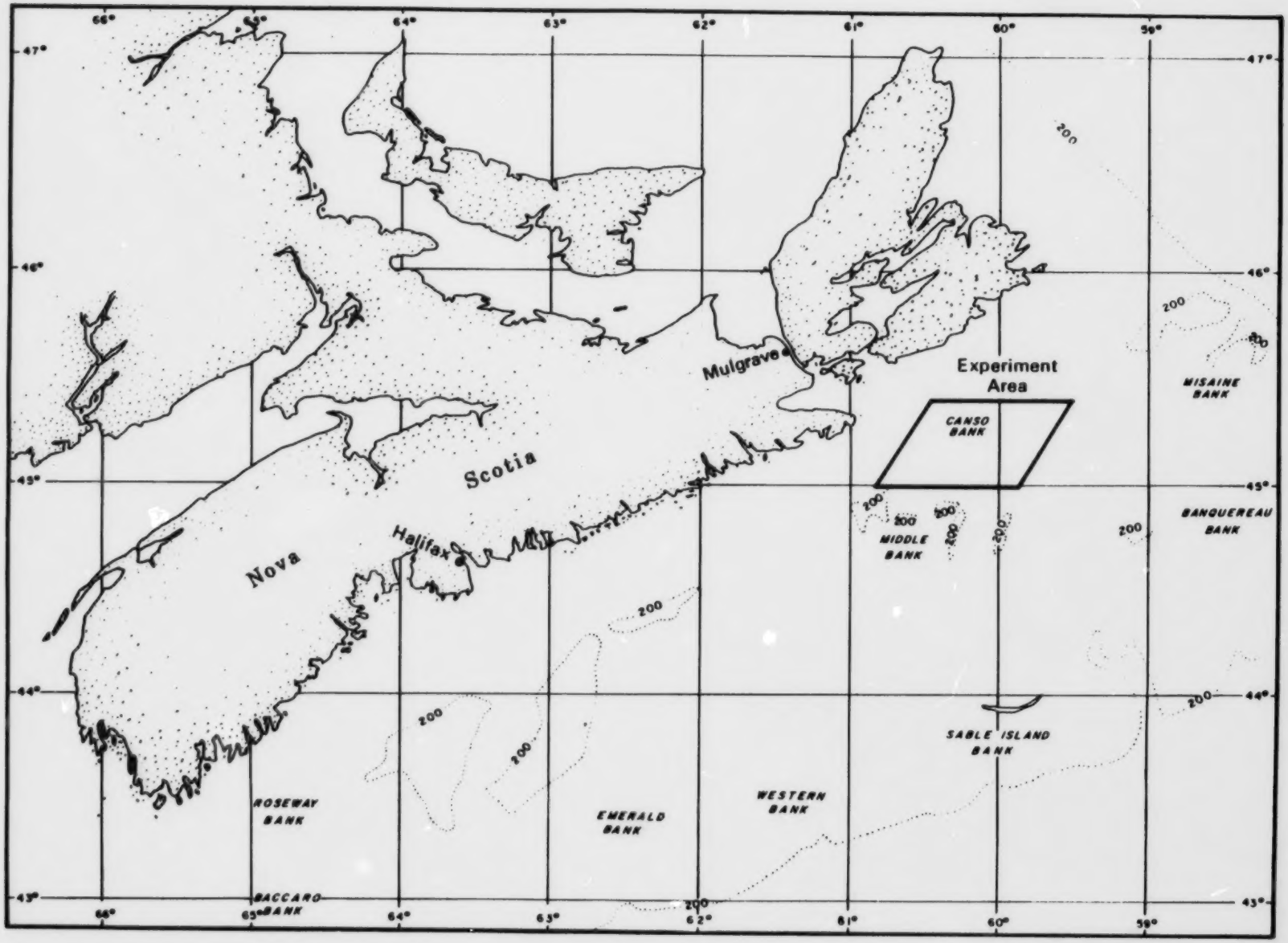


Figure 1 Location of Experiment

4. PARTICIPANTS

NORDCO Limited personnel will be conducting the experiment. Normally, the primary crew will consist of 5 individuals, two trained meteorological observers, a computer scientist, and an electronics technician. The fifth person could fit into any one of these categories. In addition, there will be one additional NORDCO representative on board during certain time periods.

There will be one United States Coast Guard (USCG) representative on board for part of the experiment. The exact length of time and the period is yet to be determined.

It is understood that from time to time there will also be extra CCG personnel and possibly a Department of National Defence (DND) representative.

Additional CCG officers will be required as radar operators during the experiment. The ship's crew will be required as lookouts during visual searches.

A 24 hour operation is planned with two NORDCO Limited employees on each 12 hour watch. One person, the field manager will normally work days only, but will be on 24 hour call. The regular search personnel will log visual detection data and meteorological/ oceanographic data as well as monitor the navigation and wave rider buoy systems. The CCG radar operators will log their own detections. The technician and the computer scientist will be responsible for handling any equipment and software problems that may rise.

Searches will be ongoing on a 24 hour basis once they are initiated. Two CCG radar operators will be required for each of the 2 radars on board the vessel. Visual searches will also be undertaken at night in order to obtain sweep width information for life rafts equipped with lights. This may require extra CCG personnel as well.

5. EQUIPMENT

5.1 General Description

The equipment to be installed on the vessel or deployed from it will include:

1. a Datawell wave rider buoy with receiver, processor, display, and recording system;

2. a navigation system utilizing LORAN-C and satellite navigation receivers (detailed description provided in Section 5.6);

3. twenty, four- and six-man canopied life rafts (10 of which will be deployed at any given time);

4. twenty moorings for the life rafts (detailed description provided in Section 5.2);

5. five LENSREF radar reflectors (detailed description provided in Section 5.3);

6. ten standard tetrahedral (12 inch) corner reflectors;

7. twenty air supply systems to maintain air pressure in the life rafts (detailed description provided in Section 5.4);

8. one Raytheon Pathfinder/ST Radar Raster Display and an adaptive interface for a Sperry 4016 radar (description provided in Section 5.5); and,

9. two temperature/humidity sensors to be mounted on either side of the ship, approximately 5 to 10 metres (m) above the waterline.

5.2 Moorings

Moorings will be required for the life rafts, the wave rider buoy, and the LORAN-C buoys. Each must satisfy specific requirements.

The life raft mooring design is shown in Figure 2. The mooring is a single point configuration to allow for easy and efficient placement and retrieval. This will allow the moorings to be moved during the experiment. The surface arrangement will enable personnel to attach and retrieve life rafts easily so that maintenance can be undertaken.

Figure 3 shows the wave rider buoy mooring system. This is a standard mooring for this instrument.

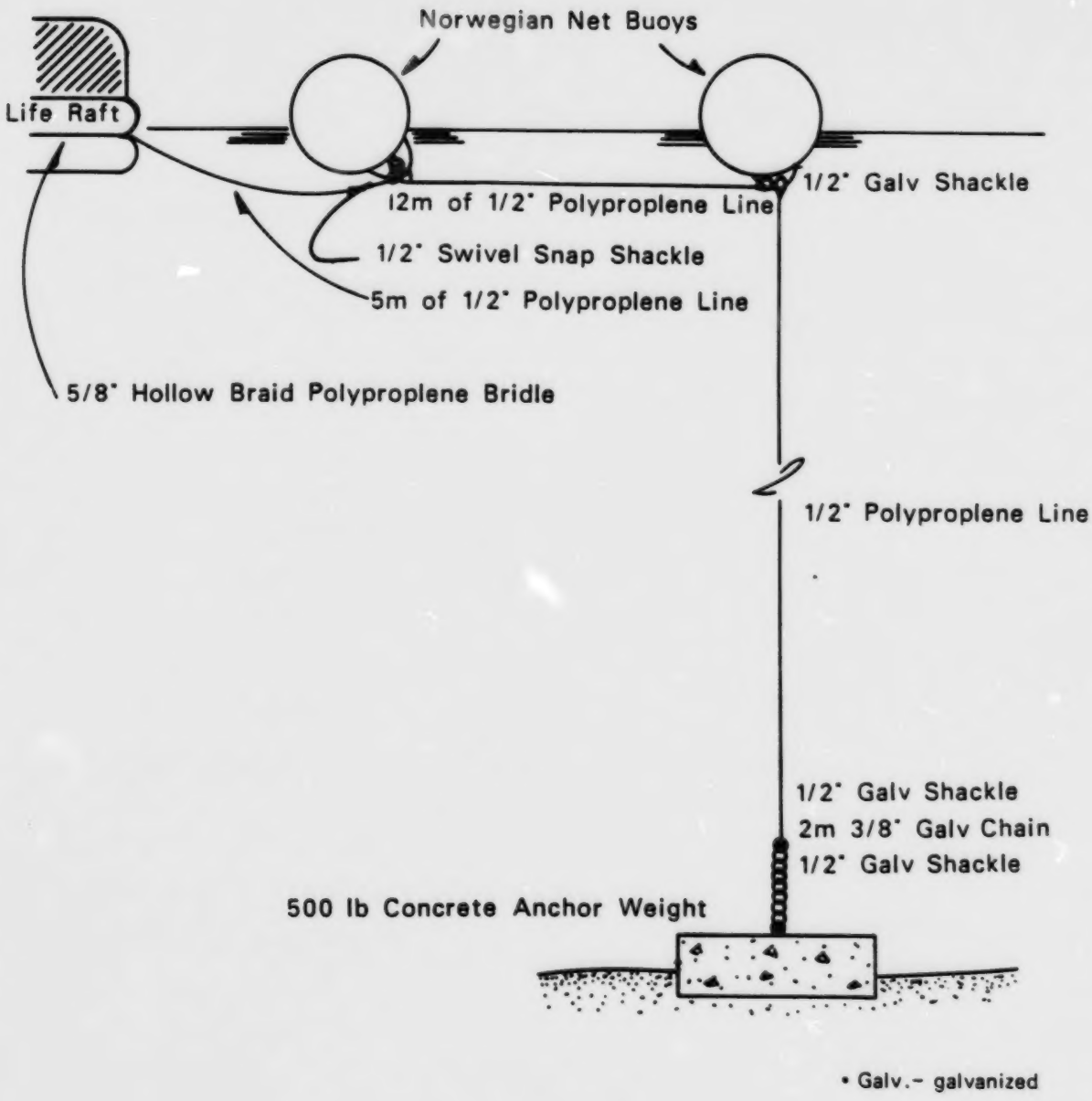
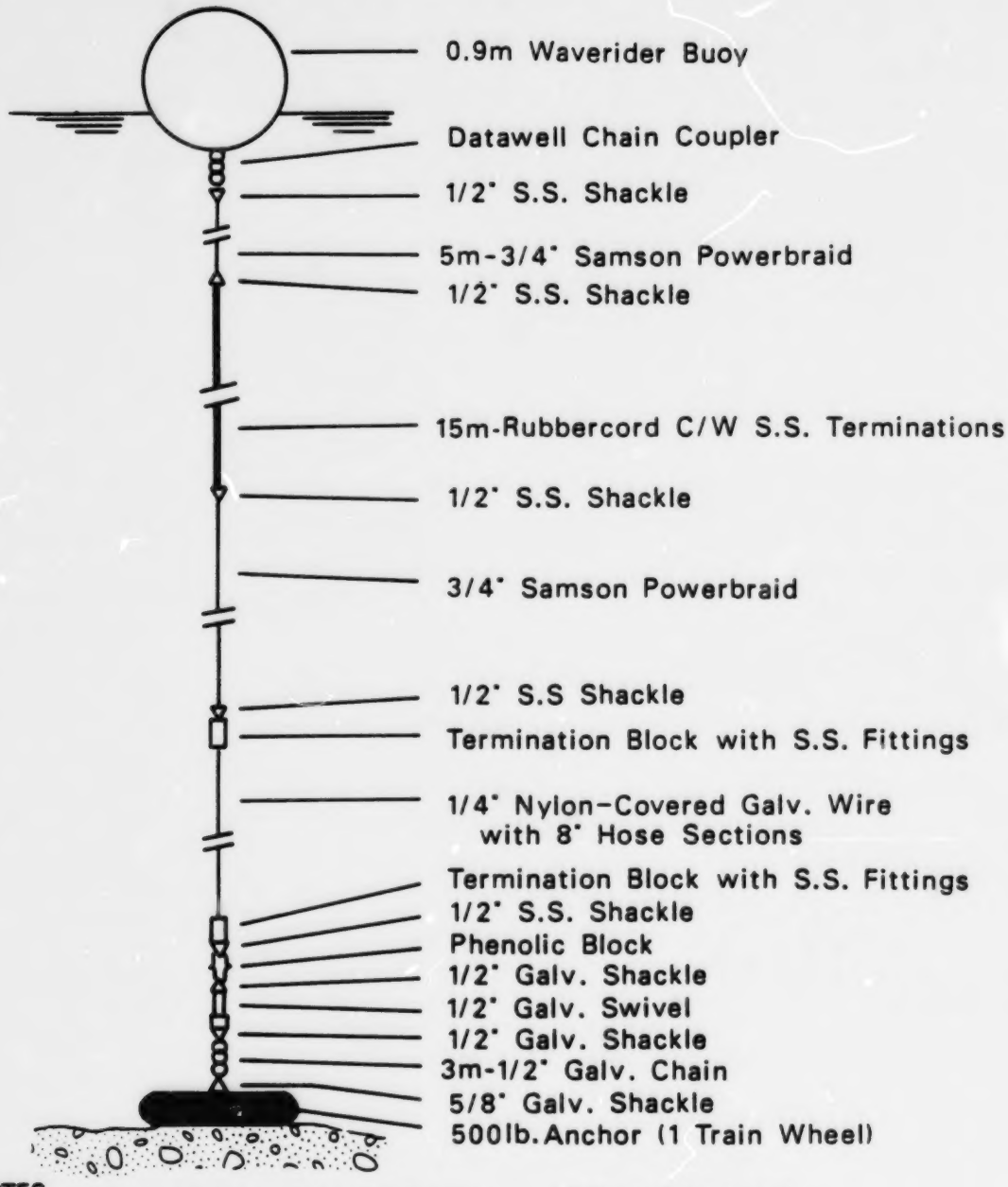


Figure 2 Life Raft Mooring Arrangement



NOTES

- All powerbraid sections terminated in nylon thimbles
- All S.S. shackles secured by S.S. cotter pins
- All galv. shackles c/w nuts and cotter pins
- S.S.-stainless steel
- Galv.- galvanized

Figure 3 Waverider Buoy Mooring Arrangement

Figure 4 shows the mooring arrangement for the LORAN-C buoy. As the buoy is designed for use in a free drifting mode, this mooring is designed to minimize the forces on the buoy during rough seas. The arrangement will also minimize horizontal movement, allowing the buoy's accuracy for differential LORAN-C use to be maximized.

5.3 Radar Reflectors

Radar reflectors will be deployed in 5 of the life rafts. These are spherical Lensref 2 square metre (m^2) radar cross section Luneburg lens reflectors (Model number DL-8A). They are omnidirectional in the horizontal plane. The reflectors will provide information on the sweep width improvement to be expected through a practical level of radar reflector enhancement. This type of reflector is preferred over the standard tetrahedral corner reflector for this experiment because of the radar cross section variability of the latter. Ten standard corner reflectors will be acquired and used as a back-up in the event that the Luneburg lens reflectors are lost or damaged.

5.4 Life Raft Air Supply System

In order to minimize maintenance time required to service and reinflate the life rafts, a special regulated air supply system has been designed to be installed in each life raft. Figure 5 illustrates the general arrangement. It is expected that this system will keep the life rafts inflated for up to about 10 days. Twenty of these systems will be available. Each system will be carefully secured inside the life raft prior to deployment to minimize chafe.

5.5 Special Radar Display System

The Raytheon Pathfinder/ST TM 34 Radar Raster Display and adaptive interface (for 4016 Sperry Radar) will be installed on the bridge of the CCGS "Sir William Alexander". The Sperry transceiver, scanner, and antenna will be utilized. Appendix 1 provides brochure information on the Raytheon system.

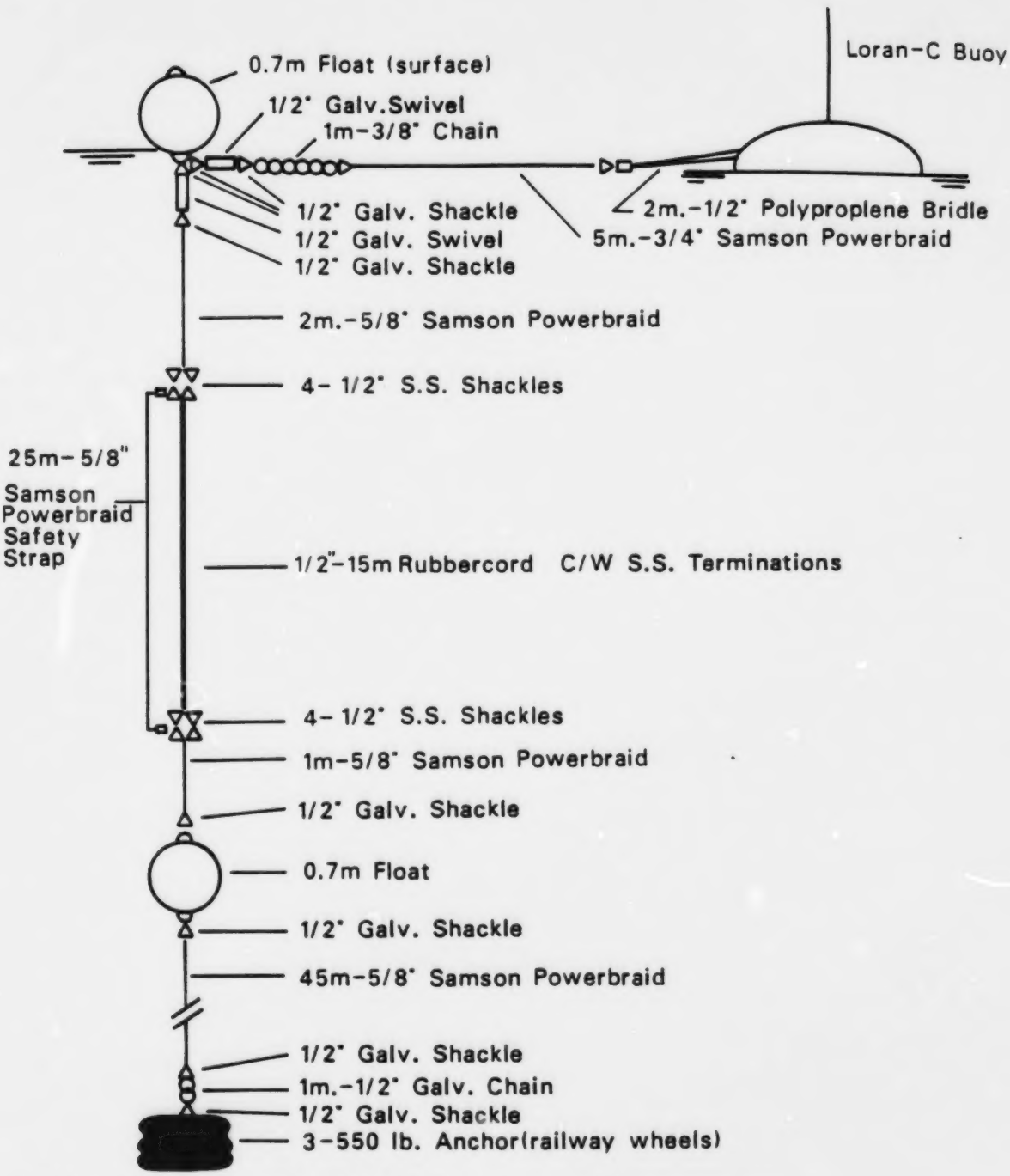
5.6 Navigation System

5.6.1 Introduction

In Phase I of the project a differential LORAN-C hyperbolic radiopositioning system was recommended as the primary navigation system to be used during the offshore SAR experiment. The basic requirements of the navigation system are:

1. the system must function reliably 24 hours per day at a distance of approximately 30 to 50 nautical miles offshore;

2. it must provide position information in real time and allow for automatic archiving of the raw data for use in the analysis phase;



NOTES:
- All powerbraid sections terminated in nylon thimbles
- All S.S shackles secured by S.S. cotter pins
- All galv. shackles c/w nuts and cotter pins
- S.S.-stainless steel
- Galv.-galvanized

Figure 4 LORAN-C Buoy Mooring Arrangement

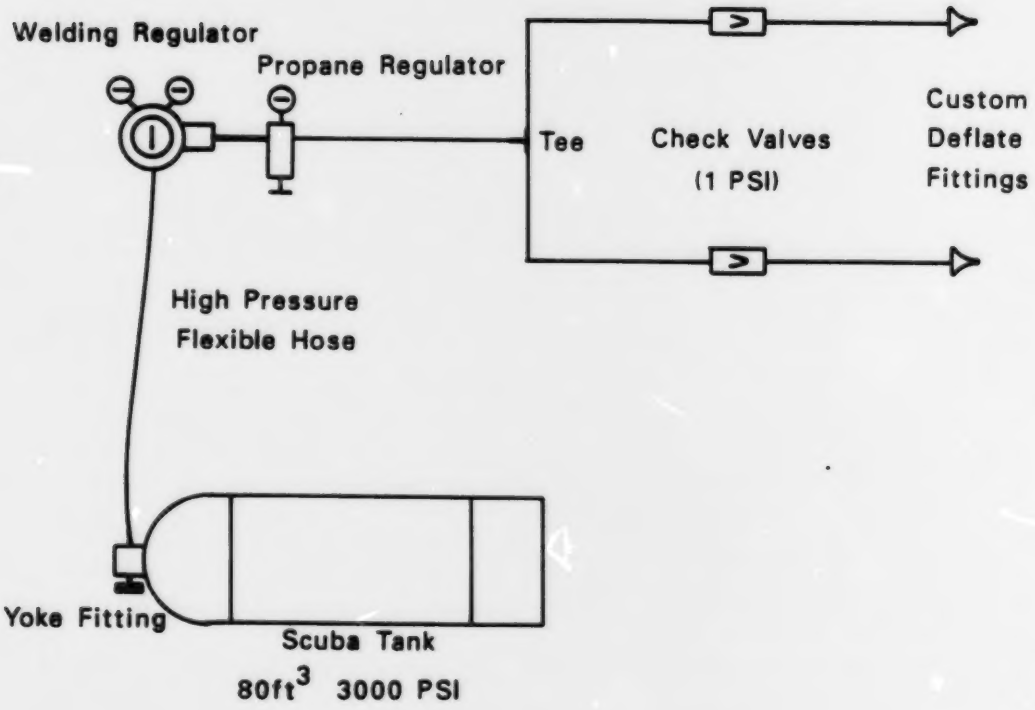


Figure 5 Life Raft Air Supply System

3. the system must be sufficiently accurate so that errors in computed lateral ranges are small;

4. it may or may not be independent of the ship's navigation system; and,

5. budgetary constraints require that the costs be kept as low as possible.

Differential LORAN-C improves position accuracy over conventional hyperbolic LORAN-C since systematic and random variations in the time difference for each master/secondary pair can be removed. Such variations are due to:

1. synchronization errors in the time intervals between the master and slave transmissions;

2. changes in the surface conductivity along the propagation path; and,

3. small differences in propagation rate of the LORAN-C ground wave signal resulting from changes in the vertical lapse rate of refractive index, a function of temperature and humidity profiles along the propagation path.

The recommended system is expected to meet the proposed radial error accuracy requirements (distance root mean square error utilizing two standard directions, 2drms) of less than 100 metres.

5.6.2 System Outline

Figure 6 illustrates the navigation system configuration. Appendix 2 contains a complete listing of the navigation system hardware. One LORAN-C buoy, moored in the centre of the experiment area, will monitor the time difference (TD) from each of the 3 master/secondary pairs on the Canadian East Coast chain (5930X, 5930Y, 5930Z). A taut mooring system will be used to reduce the horizontal excursion of the buoy (see Section 5.2). Ten minute average time differences will be transmitted by VHF link to the ship at 10 minute intervals. The TD data will be passed from the VHF receiver to a NORDCO Limited single board computer (SBC) and subsequently to a Compaq Portable II microcomputer system. The difference between the received TD's at the buoy and the long term mean TD's from that position will be used as the differential (delta ASF) correction. If required, the averaged TD data from the buoy will be filtered using an alpha recursive filter; filter weighting will be manually adjustable depending on the variability of the TD data.

Latitude-longitude fixes from the ship's Magnavox MX 5102 Satellite Navigator will be passed via the SBC to the Compaq microcomputer via the SBC and used to compute the ASF correction.

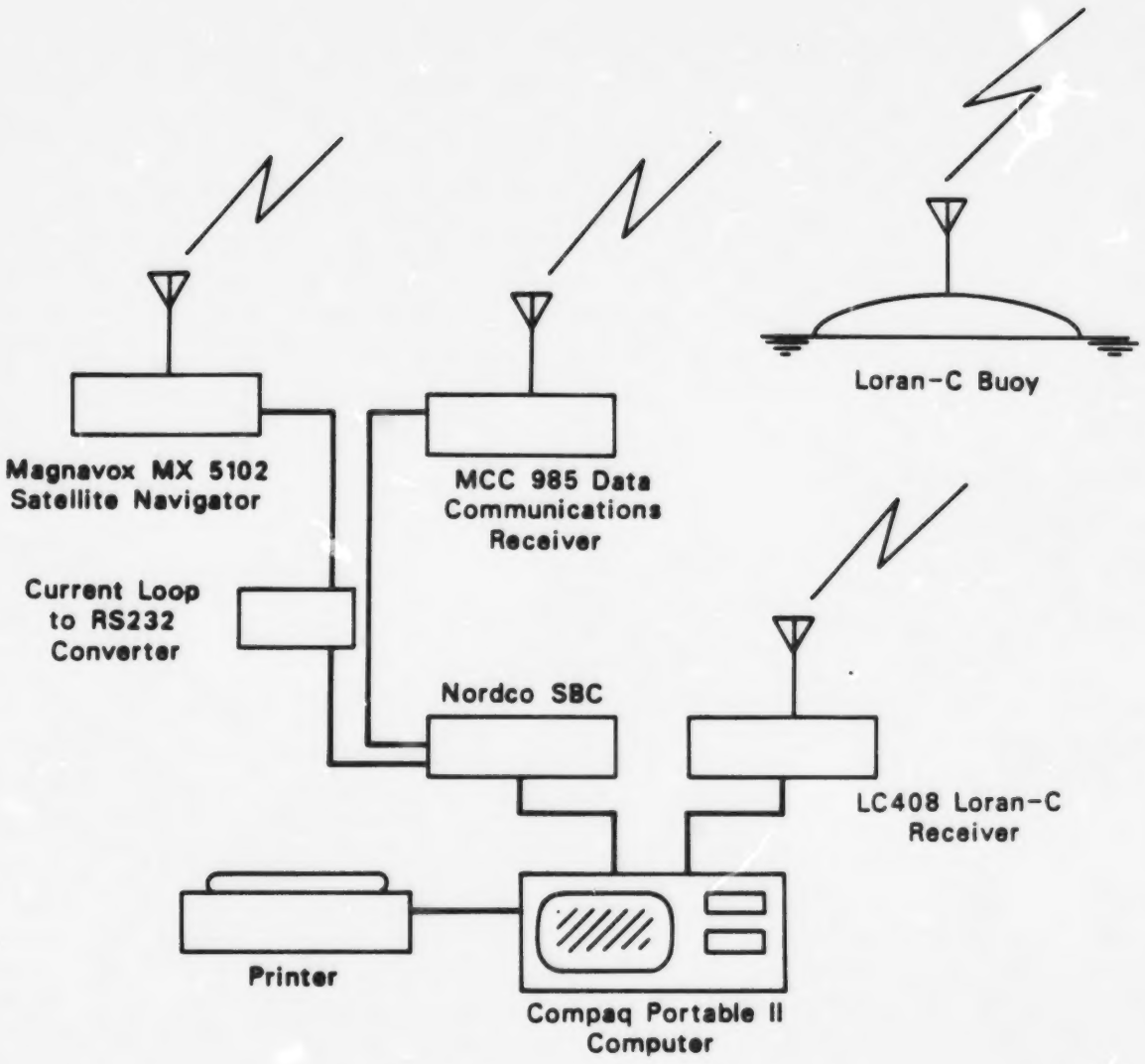


Figure 6 Navigation System Configuration

The differences for all 5930 master/secondary pairs will be monitored aboard the ship using an Internav LC 408 survey quality LORAN-C receiver. This receiver will pass TD's via an RS232 interface port to the Compaq computer every 30 seconds. These data will be filtered using an alpha recursive filter, then adjusted using current ASF and delta ASF corrections. A latitude-longitude fix will be computed for each available TD pair using an algorithm developed by Shudde (1984). When 3 TD's are available, a most probable position (MPP) will be computed from the resulting 3 latitude-longitude fixes based on the variability of the difference between the observed and filtered TD data. In the event that only 2 TD's are available, the computed fix will be considered to be the most probable position. A plotting routine will update a screen display of the ship's position and track each time a new MPP is computed.

5.6.3 Data Archiving

Raw TD data from the LORAN-C buoy and the ship based LC 408 receiver as well as the latitude-longitude position data from the satellite navigator will be archived on a disk file on the Compaq computer each time data are received. In addition, the computed MPP will be logged as well. A hard copy printout of certain raw and processed data will be made once each minute during periods when searches are conducted.

5.6.4 System Back-Up

Since the experiment is dependent on accurate navigation at all times, back-up for the primary navigation system is necessary. A spare Internav LC 360 receiver will be carried as a replacement for the LC 408. A second Compaq computer will be carried in the event that the primary unit fails.

If the entire Canadian East Coast LORAN-C chain goes down for some reason, position data will be logged directly from the Magnavox Satellite Navigator aboard the ship. This unit is interfaced to the ship gyrocompass and doppler speed log and will provide dead reckoning (DR) positions between satellite fixes. Position accuracy will vary depending on the time between fixes, ocean current, and so forth.

6. EXPERIMENT METHODOLOGY

Upon deployment of all the targets, an experiment search pattern will be planned by NORDCO Limited personnel. Prior to starting the search all information regarding search target locations will be removed from the bridge.

A normal visual search will be undertaken during daylight hours. At night, a visual search will be undertaken to look for the lights on the life rafts. The ship's officers will operate as they normally would during a search in the number and placement of visual lookouts. When a target is detected by a lookout, he will report the approximate range and bearing (relative to ship's heading) to the NORDCO observer on watch and proceed to look for other targets. The NORDCO observer will log the detection information.

A radar search will be carried out simultaneously with the visual searches both day and night. During the radar search, one radar operator will monitor the Raytheon system while another will monitor the Sperry 4016 radar on the port side of the bridge. The radar operators will act independently and operate the radars as they normally would during such a search. They will be provided with log sheets on which to report their detections and other ancillary data.

Two operators will be required per radar display. Each operator will be required to monitor the radar display for varying amounts of time. This time will either be 1, 2, or 3 hours. The monitoring time during each search will be designated by NORDCO personnel.

The Raytheon display will not be installed until early in November. The Sperry 340 CAS system will be used in its place during the initial part of the experiment.

NORDCO observers will record all the appropriate weather and sea state information every hour or whenever conditions change significantly. The wave rider buoy output will also be logged hourly. In addition, temperature/humidity recordings will be made using two temperature/humidity sensors mounted on either side of the ship between 5 to 10 metres above the water line. Only the reading from the unit on the windward side of the ship will be recorded. This information, along with the sea surface temperature, will be used to indicate the presence or absence of a radar surface duct.

Appendix 3 contains copies of the visual, radar, and environmental log sheets to be used during the experiment.

The navigation system, placed on board the ship for the experiment, will automatically log and display the ship's position. For

experimental reasons its display will not be available to the ship's officers. NORDCO observers will, however, check its operation periodically, as knowing the exact position of the ship at any given time throughout the search will be crucial to the data analysis.

The actual length of time for any given search operation will depend on a number of factors, including weather and sea conditions, target maintenance requirements, and crew fatigue. The decision will be left to the senior NORDCO representative on board and the ship's captain.

REFERENCE

Shudde, R.M., 1984. A Non-iterative Algorithm for Loran-C Position Determination. Navigation: Journal of the Institute of Navigation, Vol. 31, No. 3, pp. 179-198.

APPENDIX 1

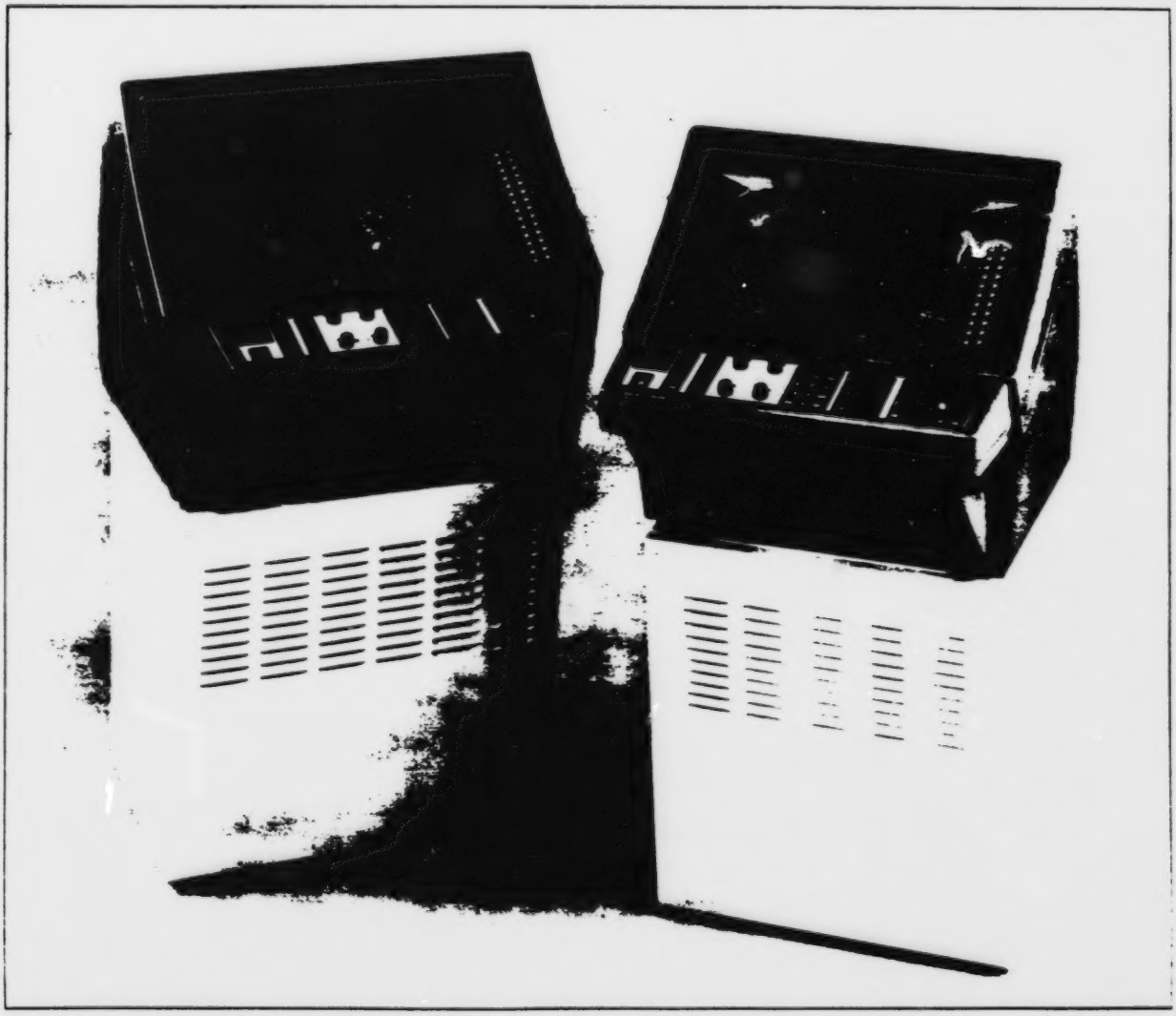
RAYTHEON PATHFINDER/ST

RADAR BROCHURE

Raytheon

SOLD AND SERVICED IN CANADA BY
CANADIAN MARCONI COMPANY
COMMERCIAL COMMUNICATIONS DEPARTMENT

PATHFINDER/ST Radar and ARPA Systems



Raytheon Introduces Revolutionary PATHFINDER*/ST Radars

The Leader for Over 40 Years

Expanding on the radar technology it developed for the U.S. Navy, in 1946 Raytheon introduced the first commercial MARINERS PATHFINDER 3 and 10-cm Marine Radars. Since then, Raytheon has been the world's leading supplier of radars for commercial, recreational, and military vessels of all sizes and types.

Raytheon's leadership results from engineering and manufacturing excellence, innovation based on leading-edge technology, and the belief that quality starts with fundamentals.

Superior Technology (ST): Another Raytheon Milestone

With the introduction of PATHFINDER / ST Radars, Raytheon again sets new performance standards for the industry.

This complete line of revolutionary commercial radars offers IMO compliant ARPA, True Motion/Electronic Plotting, and Relative Motion displays, with levels of performance never before available.

Seeing Invisible Targets

Raytheon's PATHFINDER / ST Radar combines the very latest raster display technology and vastly superior signal processing with a high performance, high reliability transmitter/receiver design. This Superior Technology – which gives this radar its name – provides performance far exceeding that of conventional PPI and raster display radars. While advances in receiver design are significant, the key to the superior performance of the PATHFINDER / ST Radar is its raster display signal processing capabilities.

This unique Raytheon signal processing is so effective that noise, clutter, and interference are "processed out" while targets are clearly and distinctly displayed. For example, it is possible for the PATHFINDER / ST Radar to "see" and display targets inside heavy rain or sea clutter, even though these targets may be invisible to other radars.

Operator Friendly

PATHFINDER / ST Radar Displays provide standard-looking PPI presentations made from scan-converted radar data which is refreshed 50 times every second. This eliminates the operator-tiring flicker found in other radar systems.

Raytheon Displays use a rectangular CRT with navigation and ARPA data logically placed around the circular PPI. The result of extensive ergonomic studies, PATHFINDER / ST Displays substantially reduce operator fatigue and confusion.

Upgrading Existing Radars

All PATHFINDER / ST Radar Displays (TM/EP and ARPA) may be used to upgrade existing 3 and 10-cm radars.

With older Raytheon Bright Display Radars, new PATHFINDER / ST Radar Displays can replace existing displays in single and dual systems using an internal interface module.

With adaptors, PATHFINDER / ST Radar Displays may also be used as add-ons for radars of most other manufacturers. In this case, Raytheon PATHFINDER / ST Radar units act as high-performance repeaters for existing displays. The interface option is flexible, adapting to most radar video, trigger, and azimuth (synchro or resolver) conventions. Installations are simple and straightforward.

34 and 25-cm diameter PATHFINDER / ST PPI displays meet IMO size requirements for 16 and 12-inch CRT displays.

Exclusive Superior Technology signal processor detects and displays weak targets typically lost in noise and clutter. Unique RAIN-RATE control, together with a computer-assisted Sea Clutter control, dramatically reduce rain and sea clutter even in the harshest environment.

ARPA Model automatically tracks 20 targets, provides IMO-required vector and readout information. Has Manual Acquisition using trackball, Auto Acquisition with true or relative acquisition zones.

Basic TM/EP Model includes North Stabilisation, True Motion, and Electronic Plotting. Course, speed, range, bearing, vectors, CPA, TCPA displayed for plotted targets... navigation line, true marks, and trial manoeuvre standard.

Safety-Coded CPA Circle, a display feature that quickly shows course selections that result in safe CPAs.

Target true wakes (electronically-generated afterglows) highlight speed and direction of moving targets.

Special, low-noise receivers and more reliable low-power transmitters equal or better the performance of high-power systems.

X-band, 3-cm, 25-kW transceiver mounted below-deck or aloft with 9-foot (274 cm) or 7-foot (213 cm) antenna.

S-band, 10-cm transceiver mounted below-deck (30 kW) or aloft (10 kW) with a 12-foot (366 cm) antenna.

PATHFINDER / ST Radar Displays may be used as add-ons for most existing radars as well as being direct replacements for the displays in older 3 and 10-cm Raytheon Bright Display Radars.

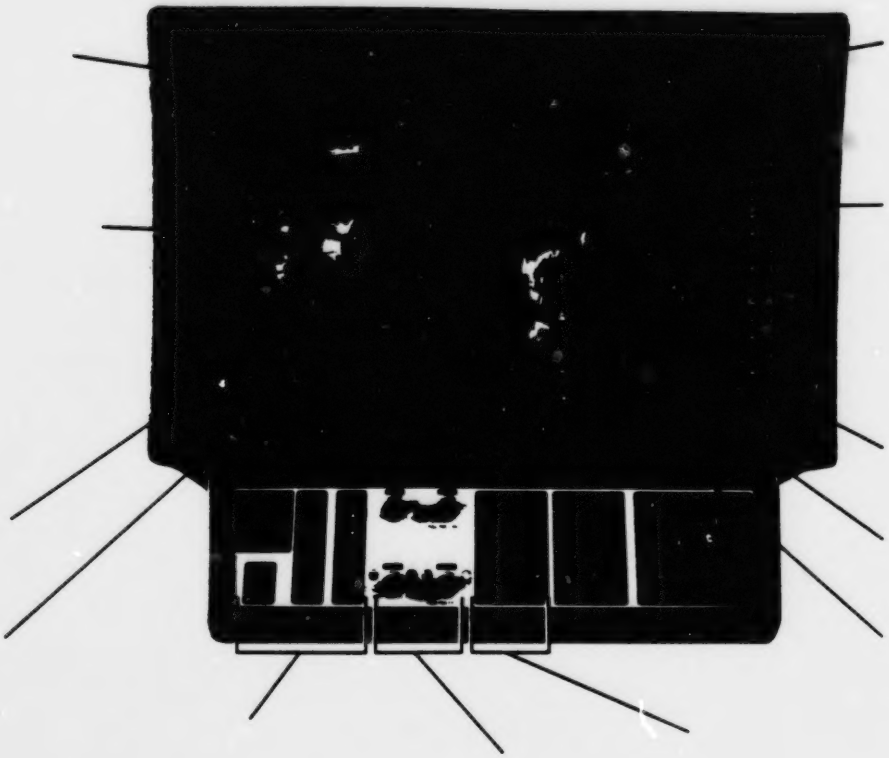
Touchkey electronic interswitching of up to 3 transceivers and display units.

Modular display consoles for operation while standing or sitting. Keyboard and CRT may be separated for custom installation.

Complete, computer-directed self-testing, performance monitoring, and trouble-shooting.

Interfaces with SNA-91 Integrated Bridge Display. Superimposes computer-generated navigation charts on the radar screen. The PATHFINDER/ST Radar and SNA-91 form the major components of an integrated bridge system.

Basic Display: Relative and True Motion, Electronic Plotting and Trial Manoeuvres



The Electronic Plotting feature permits easy target plotting that is more accurate than conventional reflection plotter methods. A total of six targets may be plotted simultaneously, and the calculated data for any two selected targets are displayed in the upper right corner of the display.

The Electronic Plotting procedure has been designed to closely follow the typical reflection plotter operation. To begin, the Plot Mode is selected and the trackball is the used to position the plot mark over the target of interest. At this point, the display processor "remembers" the plot start time. Now the trackball is free for other operations. When sufficient time has passed (three minutes, six minutes, etc.) for the target to move away from the first plot mark, the Plot Mode is entered again and the trackball used to position a second plot mark over the target. Once the second mark is entered, a vector (true or relative) appears over the target and will follow the target based on the plotted speed and course. A total of up to four plot marks may be entered for each target. When relative vectors are selected, they can be extended to show the CPA on the radar display. When a readout of target data is required, a plotted target can be designated with the trackball, and the data is presented in the upper right corner of the display.

A Trial Manoeuvre Mode is available from the "menu". When selected, plotting calculations are changed to reflect the trial course and/or speed entered.

The above display illustrates the Electronic Plotting capabilities of PATHFINDER / ST Radars.

The display is set to 6-nm range, TM Mode, north up, and offset 70% to the west. The target to the north has been plotted for three plot intervals (shown by the 3 triangle symbols) and is designated No. 1 (the designate symbol with the number "1"). The designated target data, the upper right display, shows target No. 1 is 4.3 nm, bearing 020° from own ship, and is on a course of 258° with a speed of 7.8 knots. Calculated CPA is 4.5 nm with three minutes to CPA (TCPA).

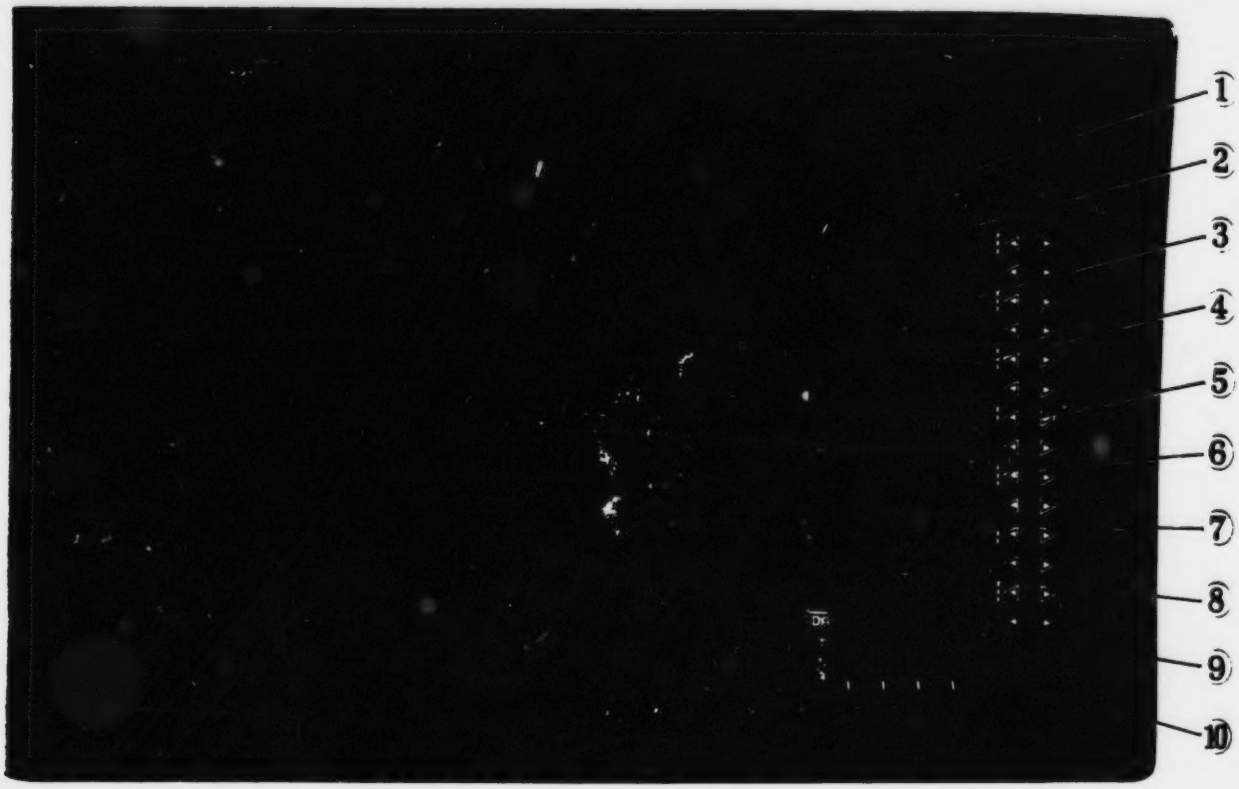
True vectors are selected with an eight-minute vector length (selected from the menu).

A second target has been designated. This target, 6 nm northeast of own ship's position, has been plotted for four plot intervals, and the designate symbol shows the number "2". The corresponding data table for this target shows a course of 142°, speed 15.3 knots, and the CPA is 4.5 nm with 28 minutes to go (TCPA).

A third plotted target, 2.5 nm east-northeast of own ship, has a true vector that indicates the vessel is on a parallel course with own ship, and the vector length is longer than own ship's vector. Therefore, this target is pulling away. If data readout is required for this target, it can be designated.

The dashed line that crosses the ship's heading marker, 6 nm ahead of own ship, is the NAVLINE. It can be used to measure range and bearing between two points on the radar display. The bearing and range of the NAVLINE are displayed in the upper right corner of the PPI display.

ARPA Provides Electronic Tracking for up to 20 Targets, Automatic Acquisition, Exclusion Boundaries and Unique Trial Manoeuvres



Raytheon's leadership in ARPA began with the successful Raycas and Raypath ARPA. Now, 34 or 25-cm PATHFINDER/ST ARPA uses superior technology to provide performance that will maintain this leadership into the 21st century.

Accurate Information When it's Most Needed

Starting with its superior target detection system, PATHFINDER/ST signal processing ensures accurate tracking in noise and clutter. Precise tracking measurements, plus computer compensation of gyrocompass and speed errors, provide reliable collision assessment data during and following own-ship manouevres.

The PATHFINDER/ST ARPA automatically tracks and displays vectors and data for up to 20 targets, acquired manually or automatically. With auto-acquisition, up to 40 targets are monitored, while the 20 most dangerous are tracked. In addition to the standard ARPA features such as manual and automatic acquisition, north up/course up, trial manoeuvres, true/relative vector, and target trails, the PATHFINDER/ST ARPA includes an extensive training mode where internal scenarios permit full demonstration and use of all ARPA functions.

1 Readout of the two designated target tracks: Track 1, target north of own ship; Track 2, target east of own ship.

2 SAFE LIMITS - Enter safe limit CPA/TCPA for dangerous target warning. Depress appropriate menu switch, then enter the value using the front panel keypad.

3 VECTORS - Three menu switches for vector selection:
- –True or relative vectors
- –Standard or variable vector length
- –Increase or decrease variable vector length.

True vectors are selected, with standard five-minute vector time for 6-nm range.

4 MODES - A status display showing all modes activated (Target Trails, Auto Acquisition, etc.) on the "SET" menu page.

5 AUTO DRIFT - Selector switch to select Auto Drift target and activate the Auto Drift function. In Auto Drift Mode, a fixed target is tracked to automatically calculate and compensate for speed errors (offset and drift).

6 DISPLAY - Selects Course-up Mode. The radar presentation is rotated to position Heading Line at 000° on the bearing scale.

7 FRONT PANEL "DISPLAY" SWITCH - Status matrix shows position of switches on front panel display section.

8 WARNINGS - Shows the current warning status. Dangerous Target, Speed Log Out, Auto Detection, etc.

9 DATA - Keyboard entry display shows the current value being entered from the keyboard.

10 MENU PAGE SELECTOR - Normal ARPA "page" currently selected "SET" page selected when initial ARPA Mode changes are required. Other pages allocated for future options (such as Navigation Package)

Signal Processing and Improved Sensitivity Set New Standards for Target Detection and Clutter Suppression

Displaying Only Targets

With PATHFINDER / ST Radars, Raytheon engineers have come very close to the ultimate goal of displaying only targets.

Signal processing virtually eliminates noise, interference, and clutter.

Receiver Improvements

Receivers of the PATHFINDER / ST Radars have been noticeably improved over those used on other radars. Low-noise amplifiers have increased signal-to-noise levels by 3 to 4 dB (2 to 2.5 times). The high dynamic range of the logarithmic receiver ensures that target returns are faithfully reproduced under even the most severe clutter conditions.

To further fine-tune receiver performance, bandwidths are automatically varied to match the transmitted pulse lengths.

Signal Processor

The heart of the PATHFINDER / ST Radar is a multiple-stage Signal Processor. Years of research and development have resulted in this near-perfect target detector.

Many aspects of the received radar signal are analyzed by the processor to greatly improve target detection in noise and clutter.

The multi-level processing begins with the Detection Thresholder. It is here that receiver output signals are digitally detected. The front panel gain and clutter controls, in conjunction with programmed radar factors (eleven in all, defining the radar characteristics), are used by the Detection Thresholder to mathematically "model" the clutter levels. This ensures that a uniform "speckle," or noise density, is maintained on the display.

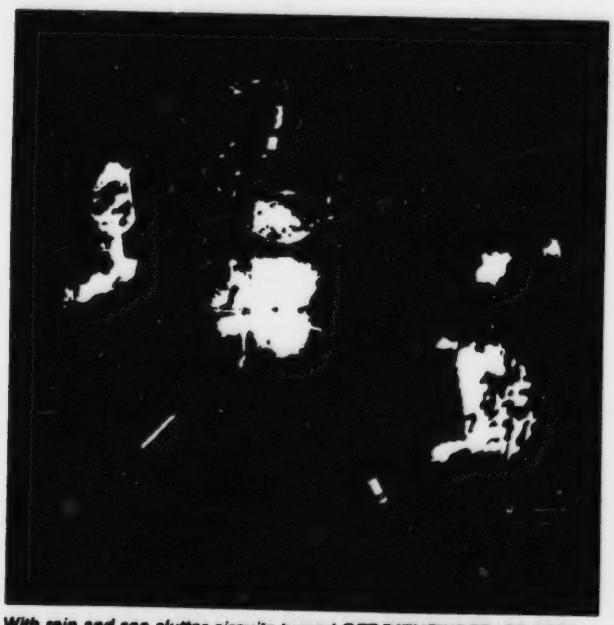
The output of the Detection Thresholder, consisting of targets, strong clutter peaks, and detected noise, is applied to the Pulse Processor. Radar returns for each transmit pulse are sampled at rates matched to the radar pulsewidth. The Pulse Processor performs binary detection, where a moving "window" samples groups of sequential returns, and the number of "hits" in the window is analyzed. If the number of hits meets the target detection requirements, the sample is saved; if not, it is rejected. This process eliminates some noise and prevents "straddling loss," i.e., the loss of targets between samples.

Each successive radar pulse transmission is sent on to the Beam Processor where beam detection takes place.

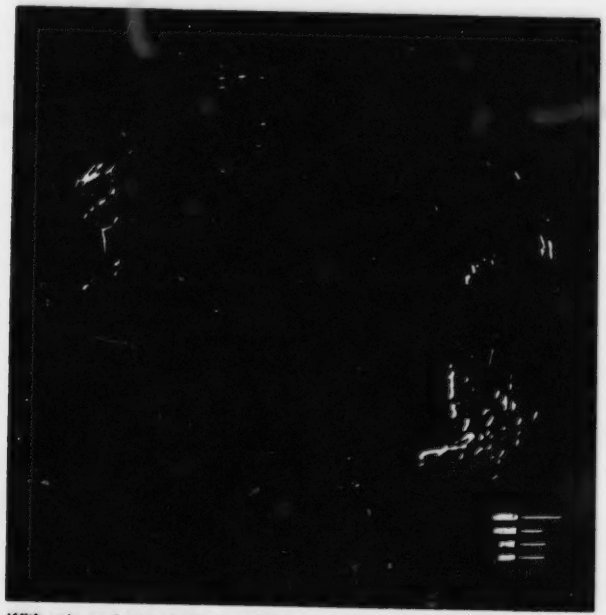
Beam Processor Eliminates Noise, Improves Detection

As the antenna beam scans across a target, the Beam Processor examines each "hit" or return from the targets. The number of hits in the antenna beam must satisfy the detection probability criteria before a target is passed to the Scan Converter. With this exclusive Raytheon process, radar interference and virtually all noise are removed. Tests have shown that Beam Processing improves detection by 3 dB or more over conventional PPI and raster display radars.

Raytheon's exclusive VLSI (Very Large Scale Integration) Scan Converter – the



With rain and sea clutter circuits turned OFF, **PATHFINDER / ST ARPA display is shown on a ferry in The Sound between Denmark and Sweden, with wind exceeding 15 knots and sea state 3. Range is set at 6 nm. Gain is set at 40%. Note that sea clutter extends 1.8 to 2 miles from own ship, and ice floe belts appear 320° to 35°, with additional ice clutter scattered beyond the sea clutter 270° to 320°. Thick lines at 230° and 155° are RACONs.**



With rain and sea clutter suppression circuits activated, **the picture above is absolutely "clean." Sea and ice clutter are gone. All targets remain, and targets previously masked in clutter are clearly visible.**

"Scan Converter on a Chip" – assembles the radar data into the proper format for the Field Processor and raster display memories. The Scan Converter has been designed to eliminate the "holes" and "overlap" found in some raster displays.

Scan-to-Scan Integration

The Field Processor is the final step of Raytheon's unique Signal Processing. Complete radar images are saved and compared with previous images so that consistent targets – those that correlate from scan to scan – are identified and separated from inconsistent targets, strong sea clutter and noise that escaped earlier processing.

The detection rules are simple: detected targets, no matter how weak in signal strength, are painted at bright levels. Noise and clutter, no matter how strong, are eliminated or, at most, painted dim.

The operation of the PATHFINDER / ST Radar is basically the same as that of any conventional radar. Gain and clutter controls are set for light, uniform noise speckle, but unlike conventional radars, Raytheon Signal Processing looks "deep" into the noise to find weak targets.

In side-by-side comparison tests between a PATHFINDER / ST Display and a conventional PPI display connected to the *same* receiver, it was found that the PATHFINDER / ST Radar displayed targets that were not detected by the conventional display. By combining a new, high-performance receiver design and bright, high-resolution raster display with superior Raytheon Signal Processing, PATHFINDER / ST Radars provide unparalleled performance.

High-definition Daylight Displays

The number of pixels has been carefully chosen to provide optimum resolution at normal viewing distances, consistent with electron beam cross-section, or spot size. For both the 23 and 19-inch rectangular CRT's, the 768 x 1024 resolution provides pixels just slightly smaller than spot size... for the sharpest pictures with no visible separation between pixels.

Computerised Testing and Trouble-shooting

In addition to having the optional IMO-required, antenna-mounted performance monitors, Raytheon PATHFINDER / ST Radars are programmed for extensive self-testing and trouble-shooting diagnostics. Software provides menus for complete system testing. Memory, timers, input and output ports, switches, potentiometers... virtually every function can be tested. If a fault is detected in a circuit board, it is identified on the display for easy, plug-in replacement.

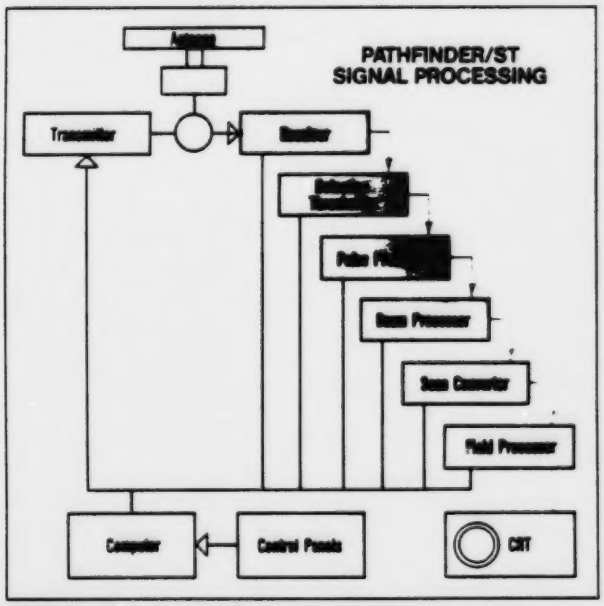
In the Self-test Mode, menus are also provided for initial entry and review of variable parameters such as antenna heights, beamwidths, power and pulse widths of transmitters... all of the data used to optimise clutter and noise suppression.

Simple, Low-cost Installation

Of all the large marine radars made to date, none can equal Raytheon PATHFINDER / ST units for economical, easy installation. For example, signal multiplexing greatly reduces the number of connections between displays and transceivers. The numerous switching and control signals that are required to operate the transceiver are compressed and multiplexed into a single, serial data stream requiring only a single wire pair. The receiver video, trigger, antenna position, and transceiver status are multiplexed into one composite video signal, which is carried on a single coaxial cable. With so few wires to connect, installation time and cost are greatly reduced. In addition, PATHFINDER / ST Radar dual systems do not need separate interswitch units.

The Models (M34) and (M25) PATHFINDER / ST Displays are designed so that the CRT display module, control panel, and electronics unit can "break away" for custom console design and installation.

And, finally, installation adjustments such as antenna bearing, heading marker, sweep delays (bank pulling/pushing) and others can now be made with keyboard entries in only a few minutes. This eliminates the need to climb a mast to make these adjustments manually.



Unique multi-stage Signal Processing has evolved from years of Raytheon research. It uses Superior Technology to provide near-perfect target sensing and sharp, bright radar pictures virtually free of clutter.

Menu selection of comprehensive tests for trouble-shooting, fault isolation and initial set-up adjustments and parameters. Simple-to-use on-screen prompts and messages guide the user through each test sequence.

Raytheon PATHFINDER®/ST Radars for Every Need

Worldwide Approval

Raytheon PATHFINDER / ST Radars exceed all applicable commercial standards and comply with tough reliability testing requirements. They have also been built to meet the requirements of IMO and the national regulatory agencies of countries around the world.

"Up" or "Down" Transceivers

PATHFINDER / ST Radar 3-cm (X-band) and 10-cm (S-band) transceivers are mounted either in antenna pedestals (Up) or below (Down) in separate cabinets with waveguide feed.

Available transceivers are:
25 kW - X-band Up or Down
10 kW - S-band Up
30 kW - S-band Down
Available antennas are:
7 or 9-foot (213 or 274 cm) X-band.
12-foot (366 cm) S-band.

Electronically Interswitched, Multi-unit Systems

Raytheon PATHFINDER / ST Radar multi-unit systems, with two or three displays and transceivers, not only offer improved performance and reliability, but are considerably less costly to install and maintain. Gone is the cumbersome, multi-contact interswitch unit. In its place, a plug-in circuit board permits keyboard switching of up to three displays and transceivers... all with the assistance of an on-screen diagram that shows the system configuration in use.

The illustration below shows a typical dual system using 34-cm ARPA and 25-cm TM/EP displays with X-band "Up" and S-band "Down" transceivers. Simple interconnection between the two displays is all that's required. Any combination of displays may be selected: single or simultaneous 3 and 10-cm operation, 3 or 10-cm operation on both displays, simultaneous short and long range navigation... whatever the situation demands.

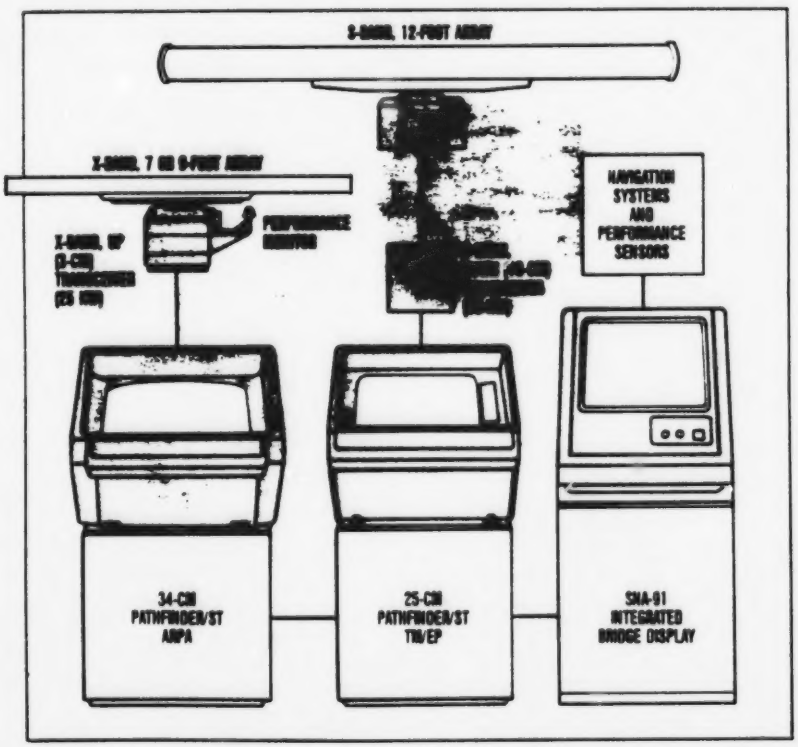
Integrated Bridge System

Raytheon, recognizing the trend towards centralized shipboard data processing and management (Integrated Bridge Systems), has designed significant interface capabilities into PATHFINDER / ST Radar Displays. The combination of the SNA-91 Integrated Bridge Display and the PATHFINDER / ST ARPA Display results in the most comprehensive and sophisticated Integrated Bridge System available today. The SNA-91 interfaces with the ship's navigation systems (Gyro, Log, Loran-C, Satnav, GPS, etc.), steering system and performance sensors, to provide complete navigation route planning, automatic steer-to-waypoint operation, ETA calculation, fuel consumption, weather, stability, engine data, etc.

Electronic charts, stored on floppy discs, are presented on the SNA-91 high-resolution color display, and selected chart information is transmitted to the PATHFINDER / ST ARPA.

This provides the unique capability of simultaneous display of two charts of different sizes. The large area chart on the SNA-91 shows detailed navigation information with superimposed target tracks; the small area chart on the PATHFINDER / ST ARPA shows the composite radar picture with critical navigation data superimposed.

With Raytheon, the Integrated Bridge System of the future is available today.



CRT swings out for easy access. Virtually all electronics are on plug-in circuit boards. Aside from the number of circuit boards used, the basic True Motion/Electronic Plotting, and ARPA display units are identical.

	X-Band		S-Band	
	MTR Up	MTR Down	MTR Up	MTR Down
Peak Power	25 kW		10 kW	30 kW
Frequency	9410 ± 30 MHz		3050 ± 30 MHz	
Wavelength	3.2 cm		10 cm	
Receiver IF	60 MHz		60 MHz	
Receiver Noise	7.5 dB		5.7 dB	5.1dB
Pulse Widths (μsec)	0.08	0.25	0.75	1.0
Pulse Repetition Frequency (PRF)	3000	2000	1000	750
Receiver Bandwidths (MHz)	20	6	4	4
Height		61 cm (24")		61.5 cm (24.2")
Width		61 cm (24")		61.5 cm (24.2")
Depth		30 cm (12")		41 cm (16.1")
Weight		46 kg (101 lbs.)		57 kg (126 lbs.)
Standard Compass Safe Distance		4.4 m (14½ feet)		4.4 m (14½ feet)
Steering Compass Safe Distance		2.7 m (9 feet)		2.7 m (9 feet)

ANTENNAS

	X-Band		S-Band
	7-Foot (2.1 m)	9-Foot (2.7 m)	12-Foot (3.7 m)
Horizontal Beamwidth	1.9°	1.5°	1.9°
Vertical Beamwidth	25°	25°	30°
Horizontal Sidelobes	–32 dB	–32 dB	–28 dB
Gain	28.5 dB	29.2 dB	28 dB
Polarization	Horizontal		
Rotation RPM (50/60 Hz)	22 / 26		
Swing Circle	2.29 m (7' 6")	2.82 m (9' 3")	3.86 m (13')
Height	61 cm (24")	61 cm (24")	88 cm (34.6")
Weight (MTR Down)	65.5 kg (144 lbs.)	82 kg (180 lbs.)	169 kg (373 lbs.)
Weight (MTR Up)	71.5 kg (158 lbs.)	73 kg (161 lbs.)	175 kg (386 lbs.)

	25 cm					34 cm				
CRT size (diagonal)	9" (23 cm)					13.4" (34 cm)				
PPI Diameter	25 cm (9.8")					34 cm (13.4")				
IMO Equivalent	12" Diam. CRT					16" Diam. CRT				
CRT Phosphor	Green (P-39)									
Resolution	768 x 1024 lines (786,432 pixels)									
Range Scales (nm)	⅛	¼	½	1½	3	6	12	24	48	96
Range Rings (nm)	⅛	⅛	⅛	⅛	⅛	1	2	4	8	16
Minimum Range	25 m (27 yards)									
Range Resolution	0.3% or 3.6 m (4 yards), whichever is greater									
Range Ring Accuracy	0.3% or 6.4 m (7 yards), whichever is greater									
Bearing Accuracy	1°									
Bearing Resolution	0.3°									
Cursor Bearing Readout Resolution	0.01 nm up to 10 nm and 0.1 nm up to 96 nm									
Height	115 cm (45")					119 cm (47")				
Width	62 cm (24")					68 cm (27")				
Depth	68 cm (27")					76 cm (30")				
Weight	77 kg (170 lbs.)					96 kg (216 lbs.)				
Standard Compass Safe Distance	3.1 m (10 feet)									
Steering Compass Safe Distance	1.8 m (6 feet)									

Raytheon Marine maintains a worldwide sales and spare parts organization with factory trained personnel around the world. Technical service groups constantly analyze field service and support to improve equipment reliability, service quality, and spare parts support for ships at sea. For further details, please ask for the latest Raytheon Service Station list.

Nav Data Readouts: Heading, course, speed, set and drift

SNA-91 Navigation: Interfaces for SNA-91 Color CRT Navigation System to receive computer nav charts to be superimposed on radar video.

Self-testing: Computer menus for complete system diagnostics and trouble-shooting

Interswitching: Touch-key, electronic interswitching of up to 3 displays and transceiver units

Installation Alignment: Antenna bearing, zero range, etc. by keyboard entry

Performance Monitor: Additional antenna rotation sensors and IMO required audible and visual warnings

AR/PA: 34 cm Color PPI with automatic acquisition of 48 targets, tracking, CPA, and TCPA for most dangerous. Auto and manual acquisition. Trial manoeuvres, nav lines, etc. IMO requirements

TM/EP: 34 or 25-cm PPI with true and relative displays. Electronic Plotting: course, speed; bearing; CPA, and TCPA for two selected targets. Plot marks and vectors for targets. Trial manoeuvres, nav lines, etc.

Pulse Length: Standard pulse length is automatically selected with range. Manual selection of next shorter or longer pulse

Trackball Cursor: Continuous on-screen readouts of cursor range and bearing

EBL and VRM: Trackball positioning with on-screen readouts

Clutter Suppression: Manual sea and rain controls with automatic compensation for pulse width, frequency, antenna height, speed, etc.

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APPENDIX 2

DIFFERENTIAL LORAN-C RADIOPOSITIONING SYSTEM EQUIPMENT

DIFFERENTIAL LORAN-C RADIOPOSITIONING SYSTEM
EQUIPMENT

1. Compaq Portable II Model 2 computer system with

   - 640 K RAM,
   - Intel 80286 CPU,
   - real-time clock with battery backup,
   - dual RS 232 serial ports,
   - parallel printer port,
   - C.G.A. graphics capability,
   - dual 360 K floppy disk drives.

2. Internav LC 408 dual chain LORAN-C receiver with antenna, antenna cable, and manuals (rental unit)

3. Magnavox MX 5102 Satellite Navigator receiver system interfaced to the ship's doppler log and gyrocompass (installed on the CCGS "Sir William Alexander" (receiver output is serial data via 20 mA current loop)

4. Interface unit (20 mA current loop to standard RS 232)

5. NORDCO Limited single board computer (SBC)

6. Two USCG LORAN-C drifter buoys (c/w waverider type mooring system, and one drag wire recovery unit)

7. MCC 985 Data Communications receiver (to receiver LORAN-C buoy TD's)

8. Lanpar dot matrix printer.

9. Expendables:

   1. printer paper
   2. 360 K floppy disks
   3. LORAN-C buoy batteries

10. Spares:

    1. Compaq computer system (rental unit)
    2. LC 360 LORAN-C receiver, antenna, cable, manuals (CCG supplied)

APPENDIX 3

DATA LOGGING SHEETS

VISUAL SIGHTING REPORT FORM

Search Number _____ Month _____ Day _____

Start Time _____ End Time _____ Year _____

Sighting No.	Sighting / Turn Time	Range (nm)	Relative Bearing (deg)	Bearing of Sun (deg)	Heading (deg T)	Lookout / Position	Remarks	Obsr.

RADAR SIGHTING REPORT FORM

Radar Unit _____

Search Number _____ Month _____ Day _____

Start Time _____ End Time _____ Year _____

Sighting No.	Sighting/ Turn Time	Range (nm)	True Bearing (deg)	True Heading (deg)	Polarization (CP/ H	Pulse Length LP/MP/SP	Range Setting (nmi)			Remarks	Operator Initial

ENVIRONMENTAL DATA LOG SHEET

MONTH _____ DAY _____ YEAR _____

VESSEL _____

TIME	POSITION		SKY CONDITION	VISBY	SEA	SWELL	TEMPERATURE			RH	SHIP		APPARENT WIND		TRUE WIND	
	Lat	Long					Dry	Wet	DP		Hdg	Speed	Dirctn	Speed	Dirctn	Speed
GMT	D	M		Nm			C	C	C	%	T	Kt	Rel	Kt	T	Kt

APPENDIX B

SIMULATOR EXPERIMENT

RADAR OPERATOR
HUMAN FACTORS EXPERIMENT
TRANSPORT CANADA TRAINING INSTITUTE,
CORNWALL, ONTARIO

June, 1988

BY

B.R. DAWE
D. BRYANT
D. FINLAYSON

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REFERENCES

1. INTRODUCTION

Based on observations made during an earlier search and rescue detection experiment (Dawe et al., 1986) and on the suggestion of the CCG Technical Advisor, an investigation was carried out to determine whether a Transport Canada navigation simulator could be used to conduct various search and rescue (SAR) experiments (Dawe et al., 1987). Two simulators, one housed at the CCG College in Sydney, N.S. and the other located at the Transport Canada Training Institute (TCTI) in Cornwall, Ontario, were examined to assess their capability in undertaking two types of experiments to:

1. carry out experiments to determine sweep width information applicable for electronic searches using marine radar; and,

2. investigate certain human factors affecting searches for relatively weak radar targets. Specifically, the interdependent factors of immediate concern were fatigue and motivation.

In order to conduct sweep width determination experiments, the simulator would have to be capable of simulating search patterns and of accurately modeling target return characteristics and the sea clutter representation. The requirements for conducting human factor experiments were less stringent since the models used to represent target characteristics and clutter would not have to be entirely accurate.

Neither of the simulator systems were found to be sufficiently sophisticated to carry out experiments to determine sweep widths.

Given the requirements, this was not unexpected; however, the simulator at TCTI, being more advanced, was deemed to have sufficient capability to be used to attempt certain human factors experiments. As a consequence of the assessment, it was recommended that an experiment be conducted to:

1. examine the look direction selectivity on the Plan Position Indicator (PPI) display; and,

2. investigate the fatigue/motivation factors in the ability of ships' officers to detect weak radar echoes.

The importance of investigating these factors became evident during the pilot CCG search and rescue detection experiment conducted in Placentia Bay, Newfoundland, in June, 1986 (Dawe et al., 1986). Observers perceived that the radar operators tended to concentrate on a

relatively small sector of the PPI display centred on the heading marker. Such a tendency may not be optimum for conducting radar searches for weak targets. It was also perceived that operators tended to become excessively fatigued after approximately two hours on watch. The data were insufficient to examine these aspects however. The purpose of the proposed radar target detection experiment using the TCTI navigation simulator was to investigate and, if possible, quantify these human factors in order that optimum use of men and equipment could be made in SAR missions employing radar searches. The specific objectives of the experiment were to:

1. define quantitatively the area(s) of the PPI display that are viewed more frequently and/or with greater concentration by experienced CCG officers; and,

2. examine the time variability of detection success for weak targets in a clutter field.

The results of the experiment were expected to be used to improve SAR planning and operations and to provide guidance in SAR training methods for electronic searches using marine radar.

2. EXPERIMENT METHODOLOGY

2.1 Overview

At the outset it was believed that both objectives could be achieved through an analysis of a simulated radar detection experiment in which a series of search patterns were run through an array of randomly distributed weak radar echos contained within a clutter field. There was, however, one caveat which primarily related to the first objective of the work: the TCTI navigation simulator is not capable of accurate simulation of the sea cluttter field and of the nature of a weak radar signal return in a seaway. In actuality, the echo of a small search object (having a small radar cross section) floating on the ocean surface is unlikely to be available for observation continuously for a variety of reasons. For example, the target is unlikely to be illumininated with every radar sweep in heavy seas and the nature and orientation of the target illuminated surface may be such that the signal is reflected away from the antenna. However, due to the limitations of the TCTI simulator software, the "echo" from each target would be available at all times while within radar range. Using the smallest available target size and adjusting the video levels of both the target return and the clutter field would make the object visually obtuse. In order to achieve objective one, this limitation of the simulation had to remain unknown to the radar operators. The analysis of the fatigue/motivation factor would not be affected by this limitation.

2.2 TCTI Solartron Navigation Simulator Facility

The system consists of a master control/monitor station and four individual bridge simulator facilities (own ships). Each is equipped with a radar display, navigation equipment, communications gear, and helm control facilities. The equipment is controlled by proprietary software running on a DEC PDP-11/34 computer system. Each own ship can be navigated independently or made to follow a prescribed route. A brief summary of system characteristics considered relevant to the experiment follows directly:

1. Any specified search pattern and vessel speed can be simulated.

2. Up to 24 radar targets can be positioned in any desired location.

3. Target strength and size may be varied in steps allowing relatively weak targets to be simulated. Target characteristics, however, are not adjustable during an individual trial.

4. Clutter simulation is not accurate but its intensity and range can be adjusted. The video levels of the targets and clutter field

can be adjusted independently by the system operator during a simulation.

5. The simulated pulse length is menu adjustable between 0.2 microseconds (us) and 3.0 us, and antenna beam width is variable between 0.7° and 2.1° to the 3 db point in steps of 0.17°.

6. A flat bed plotter is available to plot track and target positions at virtually any time interval desired.

2.3 Procedure

For the purposes of this experiment each own ship acted as an independent SAR vessel. Track patterns were established and all vessels maintained identical courses and speeds at all times. Since each ship had the same opportunities to detect the targets, no communication between the individual vessels was permitted.

The experiment was run over the five day period from July 13 through July 17, 1987. Two simulated searches of approximately four hours duration were run each day, usually from 0800 to 1200 EDT and from 1300 to 1700 EDT. Eight CCG officers were made available for the experiment and they were arbitrarily divided into two groups of equal size. The individuals in each group participated as radar operators on the identical series of simulated search patterns. The participants were:

Allan Blanchard, AMAD, CCG, Ottawa
Joanne Clouatre, CCGS Simicoe
Robert Gale, MFB, CCG, Ottawa
Jon Griffin, AMR, CCG, Ottawa
Ray Landon, CCGS Simcoe
Julie Inkel, AMR, CCG, Ottawa
Paul Rudden, RCC, FCB Halifax Dockyard
Mike Voigt, CCG, Dartmouth.

These officers had either a Watchkeeping Mates Certificate, an Ocean Navigator 2 Certification, or a First Mate Home Trade ticket. Sea time experience ranged from about 1 year to 25 years with the median being very near three years.

2.3.1 Search Pattern and Target Distribution Arrangement

The initial search patterns and target distribution arrangement were prepared prior to arriving at TCTI. Familiarization with the simulator facility and the implementation of the individual exercises was conducted in the four day period from July 9 through July 12, 1987. In this work, researchers were provided with very helpful guidance and assistance from Mr. Daniel Tremblay, acting chief A/ZPTACG, TCTI and from Mr. Thong Nguyen, Instructor, Blind Navigation Simulator, TCTI.

Eight parallel track or creeping line type search patterns, and two expanding square patterns were implemented. Twenty-four targets (the maximum possible) were distributed at random locations within the search area. The area was a function of the leg lengths and the vessel speed. The actual number of detection opportunities varied since some targets became opportunities more than once while others, normally because of their location on the extreme edge of the search area, never did become opportunities for detection.

An attempt was made to use ship parameters which were, more or less, typical of CCG SAR vessels. The specific ones of interest here were vessel speed and radar antenna height. Simulated search speeds, which were held constant during an individual search, varied between 10 and 15 knots. A radar antenna height of about 11 metres (m) was selected.

The target "echoes" were made as small as the system allowed. Video levels of both the targets and the sea clutter representation were adjusted to make the detection of the targets difficult. The clutter model employed in the simulator is not realistic; in particular, the clutter pattern is symetrical and not typical of sea clutter. The intensity varies radially, decaying gradually with distance from the centre of the PPI display to a minimum at 3 nautical miles (nmi). The simulated searches were conducted in deep water out of sight of land. This eliminated the requirement for navigational support.

2.3.2 Data Collection and Quality Control

The simulated searches were run with one CCG officer operating the radar unit in each own ship for the length of the search; normally the duration was approximately four hours. The operators were required to log the time, the true bearing and range of each target sighting, and were asked to provide remarks whenever it was deemed appropriate. No communication regarding the experiment was permitted between the operators.

The operators were encouraged to behave as they normally would during a search operation and were provided with manual plotting aids such as grease pencils. In addition, certain amenities such as coffee were made available to the operators.

Quality control of the detection logs was carried out by the coordinator to ensure that the logs contained all the relevant information and that the formats were consistant.

3. DATA REDUCTION AND ANALYSIS

3.1 General

Upon completion of the experiment at TCTI, the detection data were entered into files on the NORDCO Limited DEC VAX-11/750 computer system. The data set was quality controlled manually and all data entry errors were corrected. The search tracks and target distribution files, which were originally generated on a microcomputer system, were transferred to the VAX-11/750 computer, completing the data assembly.

Computer software was developed to generate detection opportunity files, to compute actual bearings and ranges of the targets at the times of detection, and to compare those data with the logged entries. Invariably, there were differences between the actual bearings and ranges and the reported relative positions. Tests were conducted to determine acceptable error limits.

3.2 Detection Envelope and Look Direction Selectivity

The detection envelope is the moving area around a search unit within which a target has a potential for being detected (Edwards et al., 1981). The actual detection envelope for a marine radar system is a complex function of target radar cross section area and height above the sea surface, sea state, radar performance specifications, antenna height, microwave propagation conditions and many other factors. For the purposes of this analysis the detection envelope has been defined as the radar range selected by the operator. For the most part, the radar operators elected to use the 6 nmi range setting on the PPI display. Since the theoretical radar range of targets very near the sea surface with an antenna height of 11 m is approximately 7.5 nmi, the commonly selected radar range was appropriate. To examine the look direction selectivity on the PPI display, the detection data were binned by bearing, by range, and by range and bearing. Actual and relative frequencies of detection were computed from the binned data.

3.3 Time Variability of Detection Success

Investigation of the fatigue/motivation factor was reduced to an examination of the variability of target detection success in relation to time on search. For each operator and search, the ratio of the number of confirmed detections to the total number of opportunities in consecutive ten minute time intervals was determined. The average number of the percentage of targets that were detected for each time bin was computed to show the variability of detection performance with time.

4. RESULTS

4.1 Look Direction Selectivity

As stated in the methodology (Section 2.3) two groups of 4 radar operators were formed, with each group alternately undertaking simultaneous radar searches through the field of targets. A different series of search patterns were developed for each group.

Figures 1 and 2 show the polar diagrams for each group. Figure 3 shows the summation of Figures 1 and 2. The arcs and radials form areas of equal size. The numbers inside these areas show the total number of detections in the areas. The inserts give the total number of detections by quadrant. These figures, along with Table 1, which gives a breakdown of the total opportunities and detections by sector, show a number of trends common to both groups.

First, the highest percent detected was in the second quadrant; the lowest is in the third quadrant, even though there were approximately 10% more opportunities than in any of the other quadrants. Secondly, comparing the port and starboard sides, the highest number and percent detected was on the starboard or right side of the PPI. Finally, in comparing aft and forward sectors, even though there were more opportunities in the aft section, the percent detected was about equal in both.

Figures 1, 2, and 3 in conjunction with Figure 4 shows another trend. That is, more detections occurred in the 3 to 4 nmi range than anywhere else. It is noted that the simulated clutter decreased markedly after 3 nmi. However, a significant number were seen inside the 3 nmi range (area of greatest clutter).

4.2 Time Variability of Detection Success

Figures 5 and 6 show the percentage of targets detected as a function of time and the number of opportunities as a function of time (based on 10 minute averages) averaged over all searches for each group. The number of opportunities is rounded off to the nearest whole number. Figure 7 shows the combined result for both groups. The overall detection capability of Group 1 is slightly lower than that of Group 2. The figures suggests an inverse relationship trend between the percentage detected and the number of opportunities. To determine overall time trends of operator performance it was necessary to remove this effect. This was done by dividing the percent detected by the number of opportunities. Figures 8 and 9 show the result of this normalization for each group. Figure 10 shows the result when both groups are combined. There is an overall tendency to be slightly better at the beginning and towards the end of the search (more evident

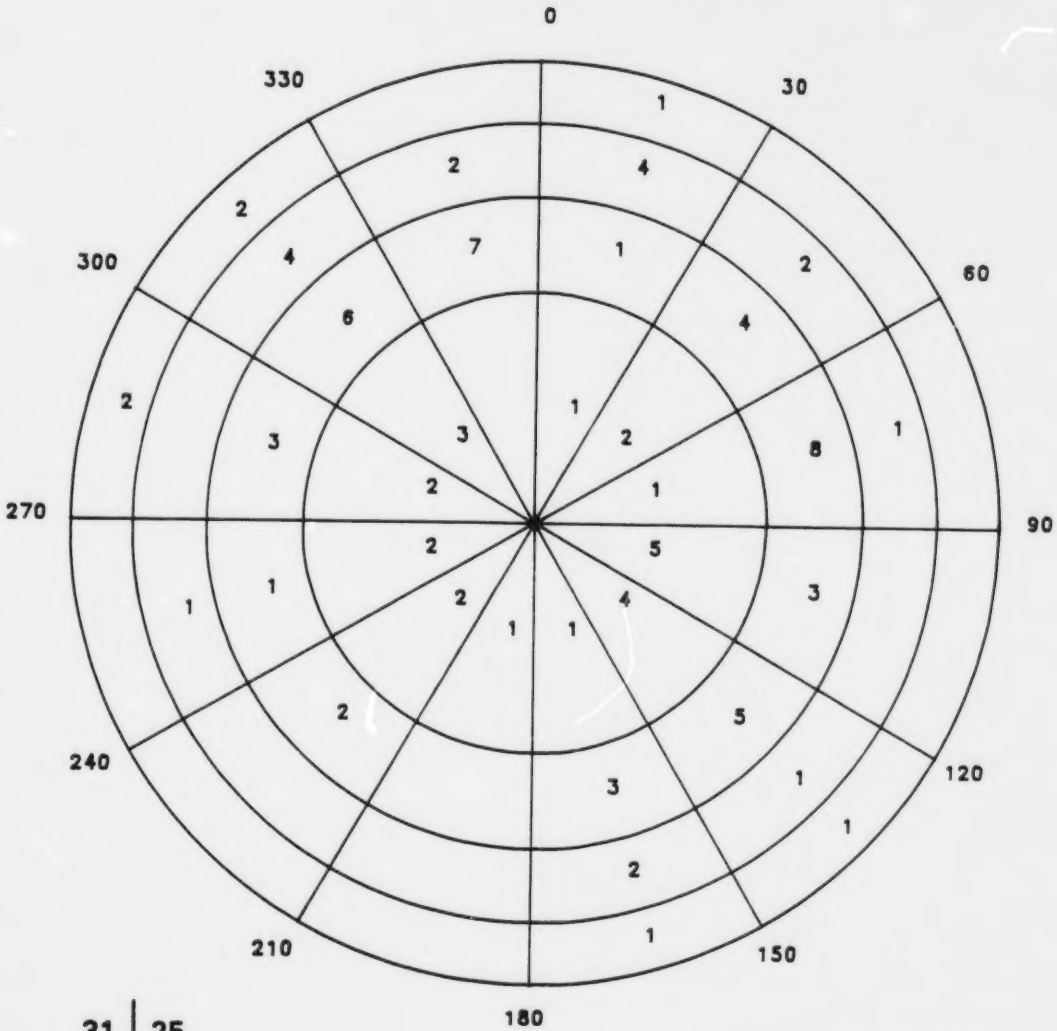


Figure 1 Relative Target Detection Positions for Group 1

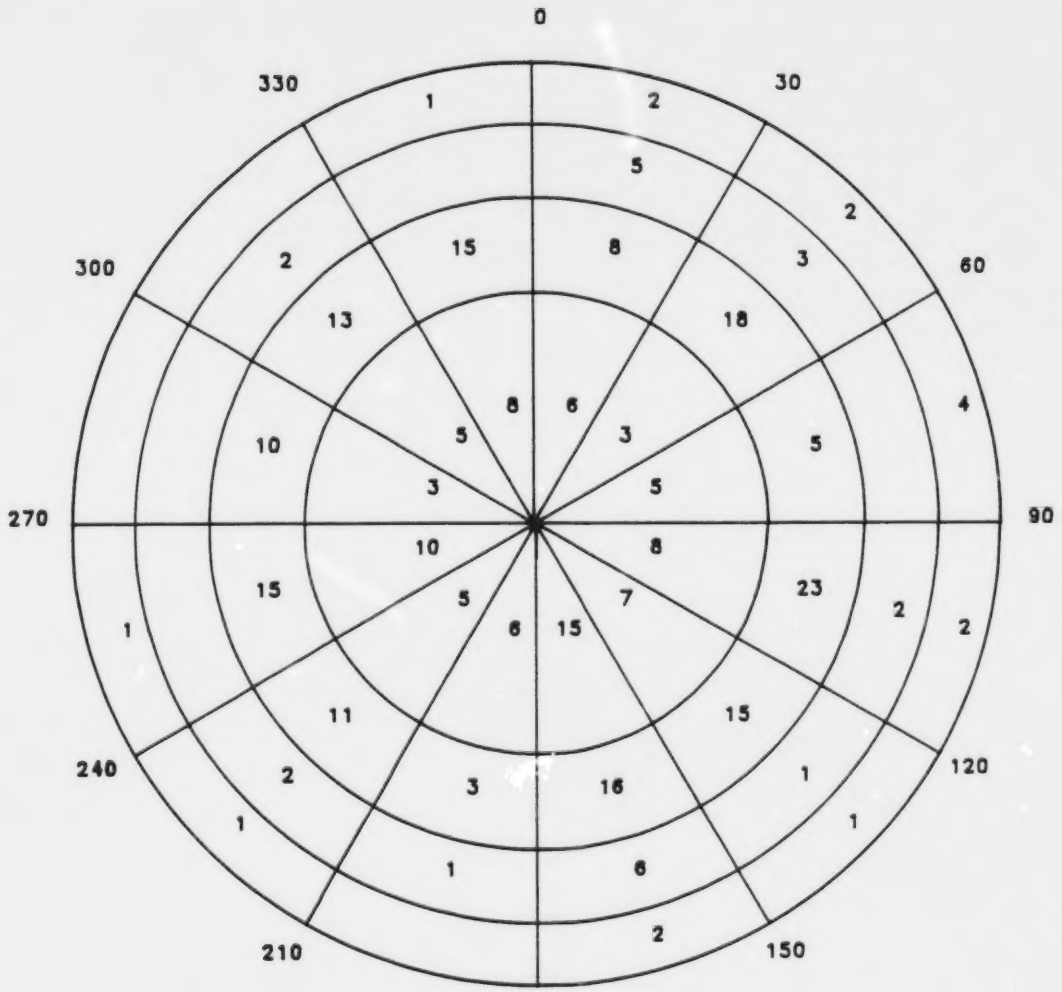
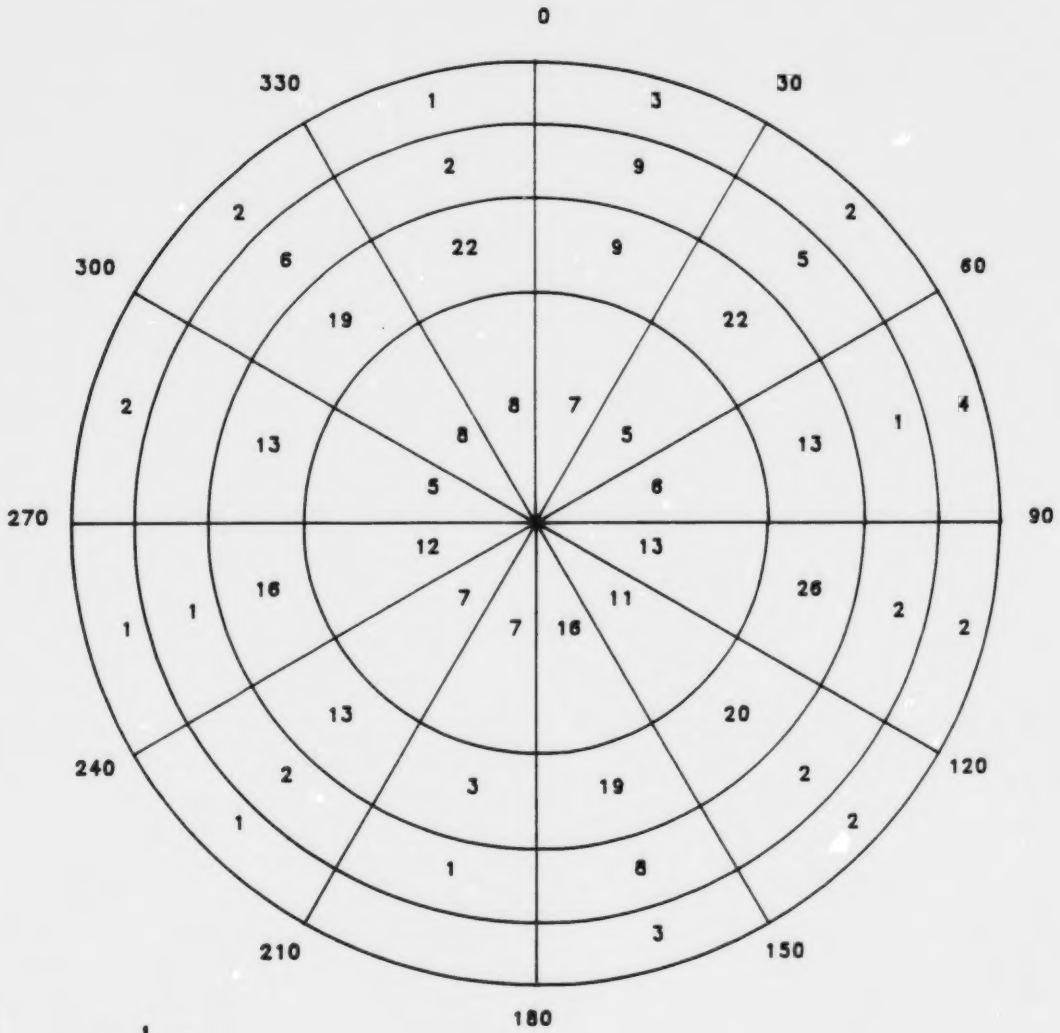


Figure 2 Relative Target Detection Positions for Group 2



88	86
64	124

Detections by Quadrant

Outer range ring: 6 nmi

Figure 3 Relative Target Detection Positions for Groups 1 and 2

Display Sector	Total Number of Opportunities	Total Number of Detections	Percent Detected
First Ouadrant (000°-090°)	3339	86	2.58
Second Ouadrant (090°-180°)	3672	124	3.38
Third Ouadrant (180°-270°)	3969	64	1.61
Fourth Ouadrant (270°-360°)	3567	88	2.47
Forward Sector	6906	174	2.52
Aft Sector	7641	188	2.46
Starboard Sector	7011	210	3.00
Port Sector	7536	152	2.00

Table 1 Breakdown of Total Number of Opportunities, Total Number of Detections, and Percent Detected for Various Sectors of the Radar PPI Display

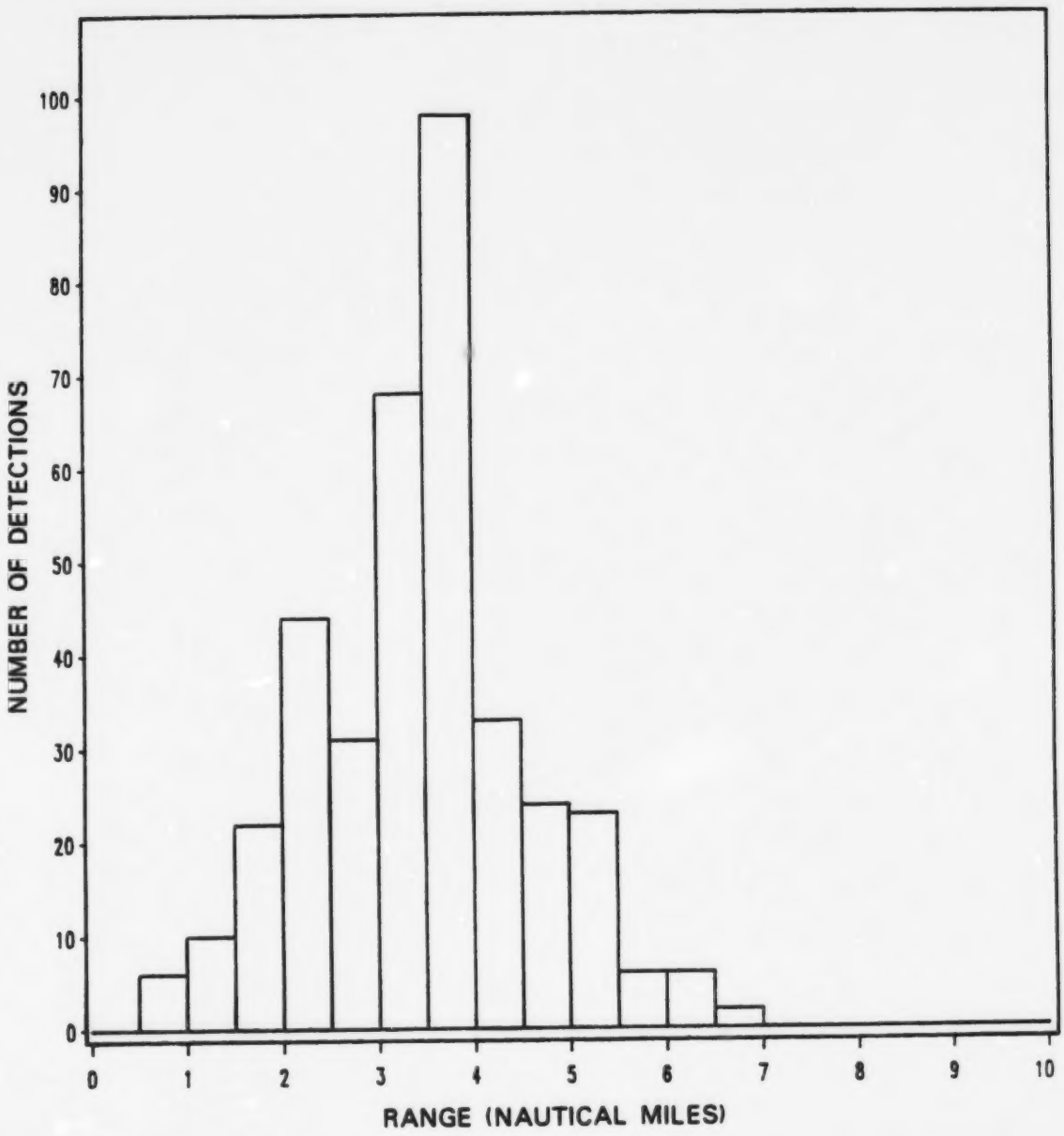


Figure 4 Number of Detections by Range for Groups 1 and 2

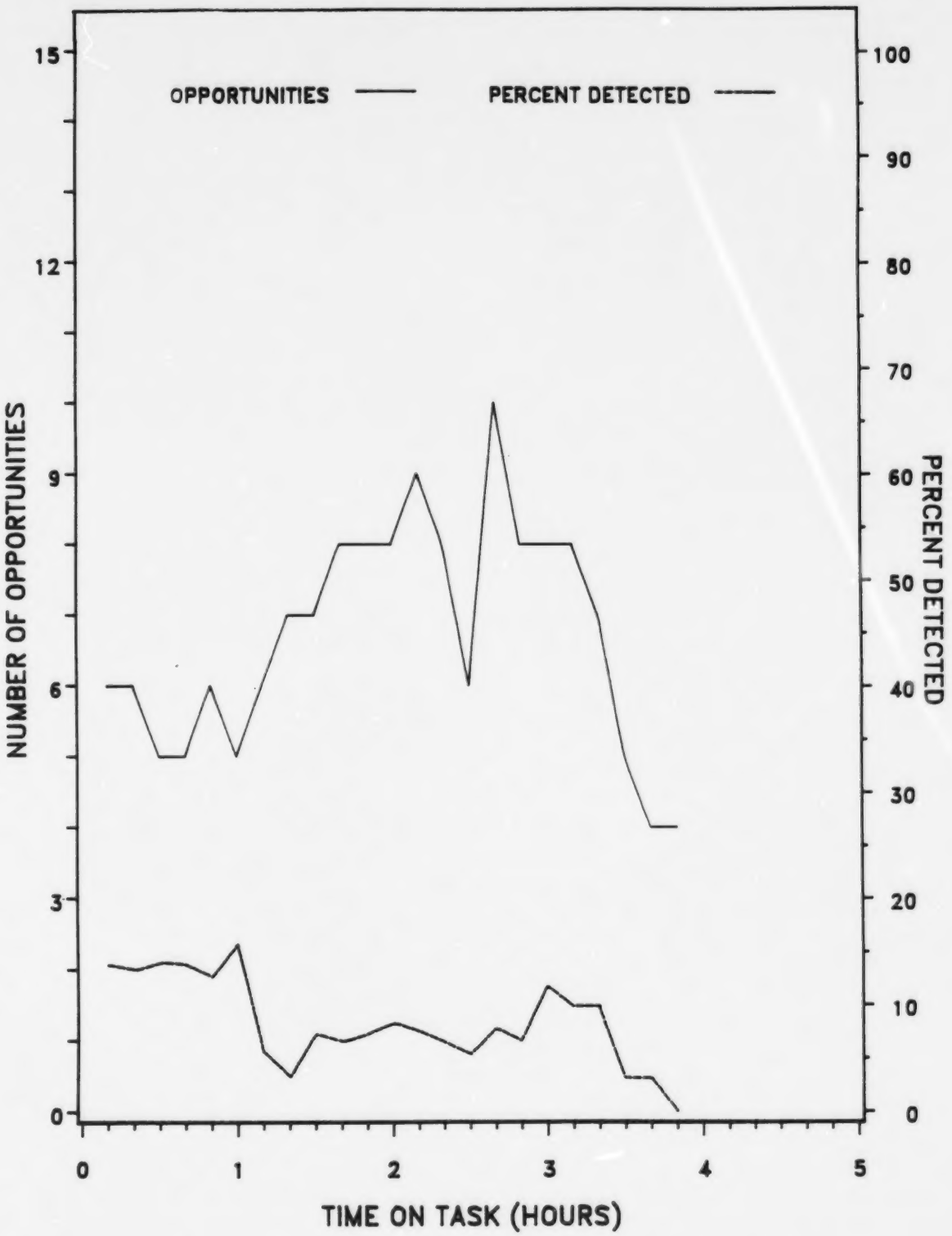


Figure 5 Average Number of Opportunities and Percent Detected as a Function of Time for Group 1

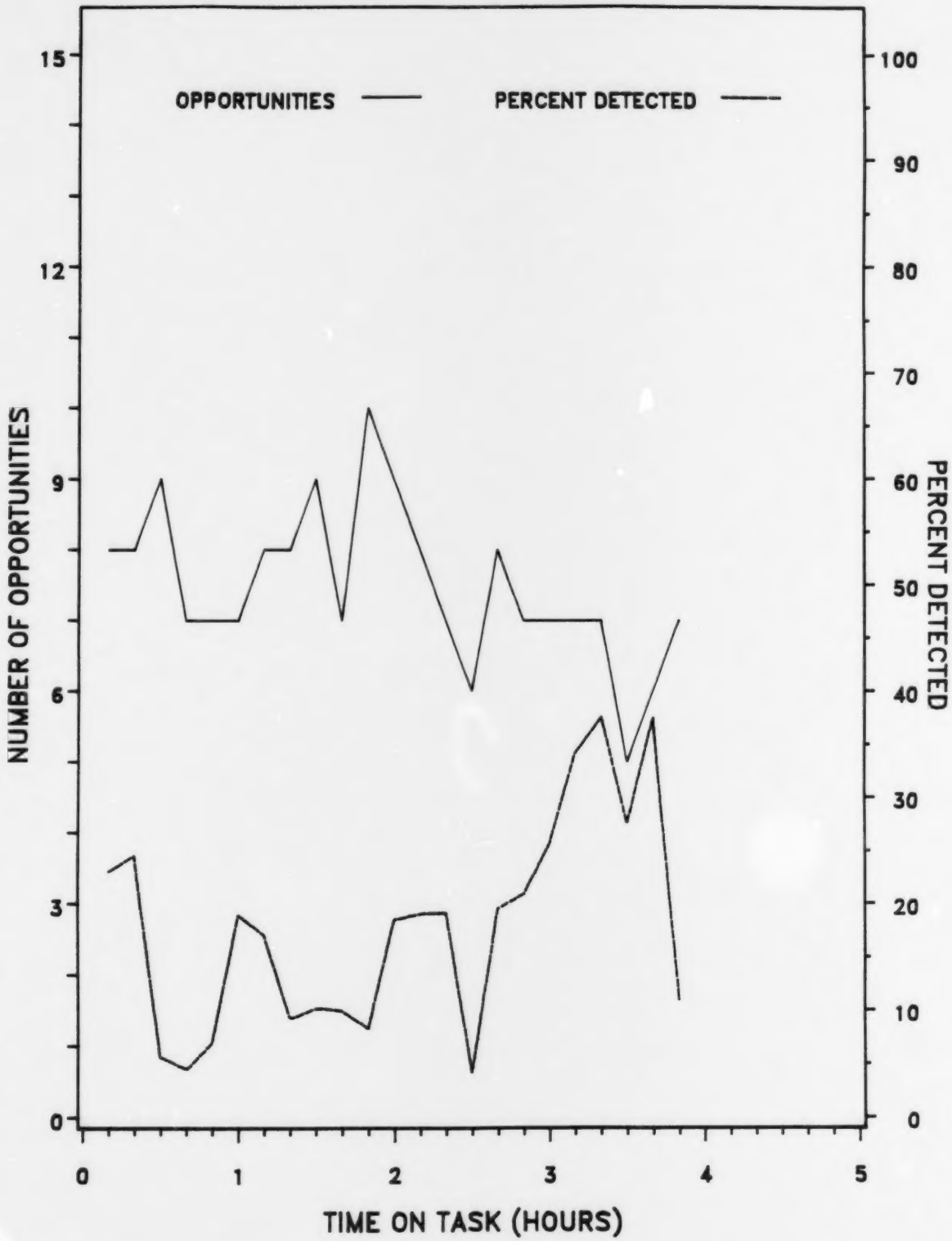


Figure 6 Average Number of Opportunities and Percent Detected as a Function of Time for Group 2

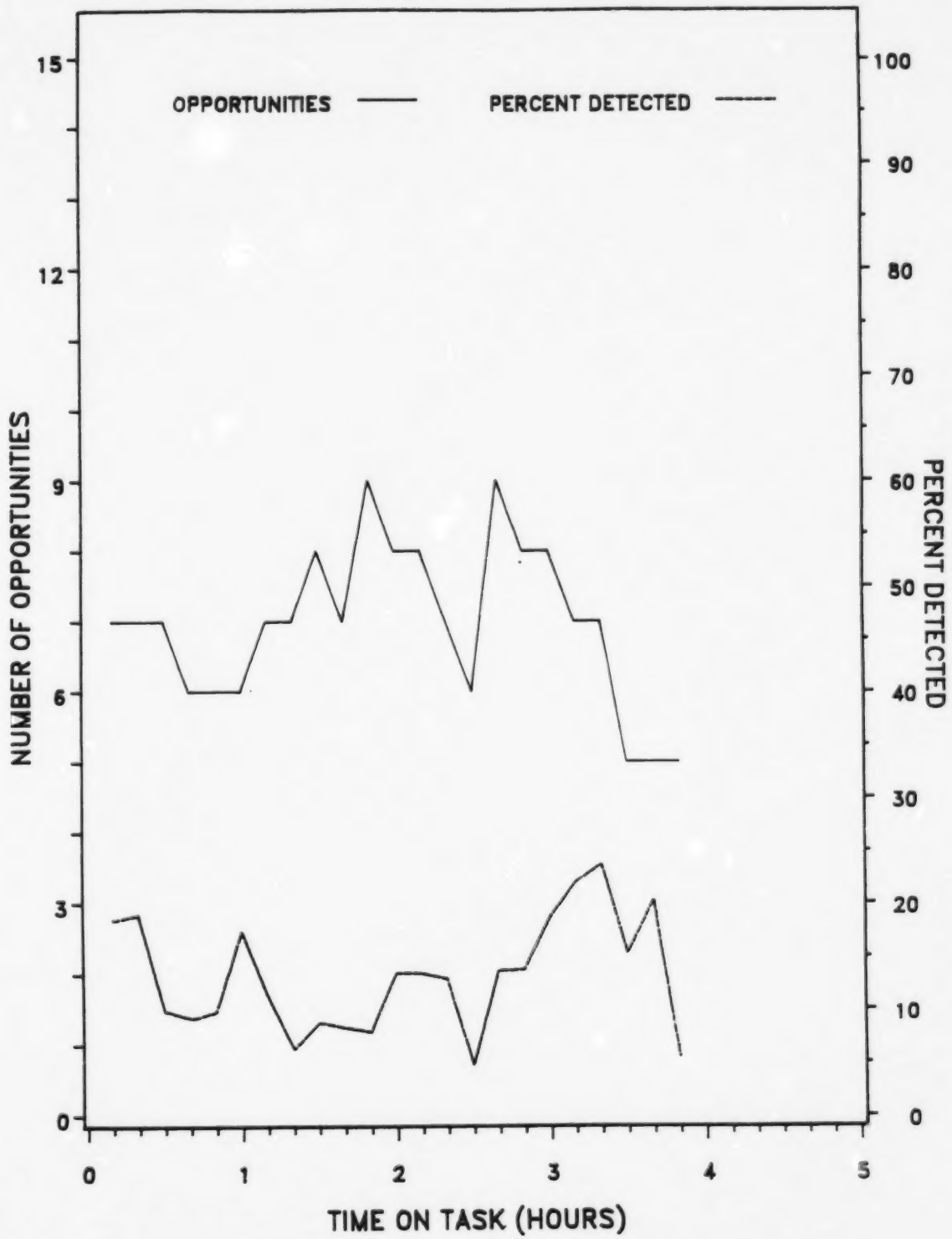


Figure 7 Average Number of Opportunities and Percent Detected as a Function of Time for Groups 1 and 2

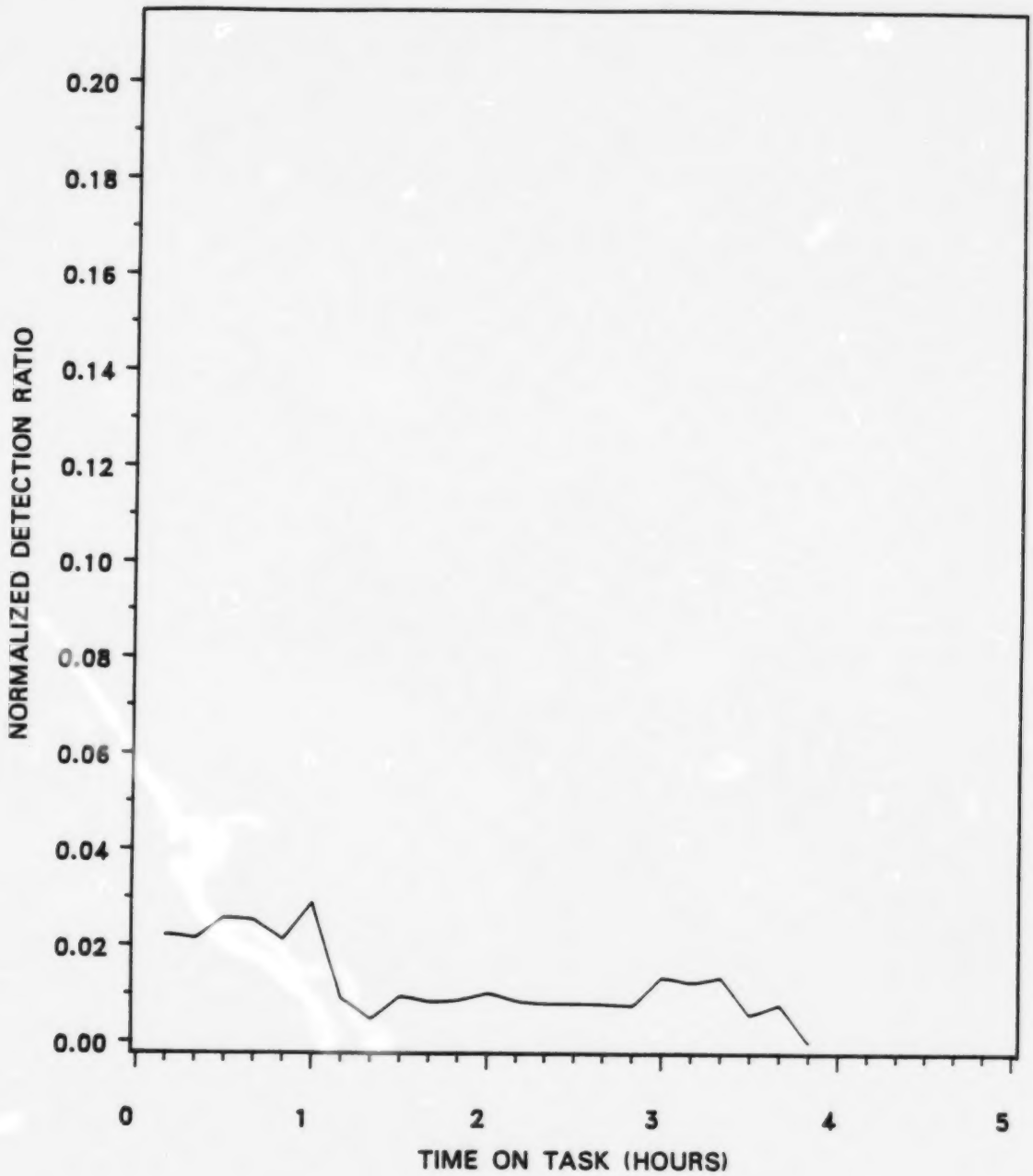


Figure 8 Average Normalized Detection Ratio as a Function of Time for Group 1

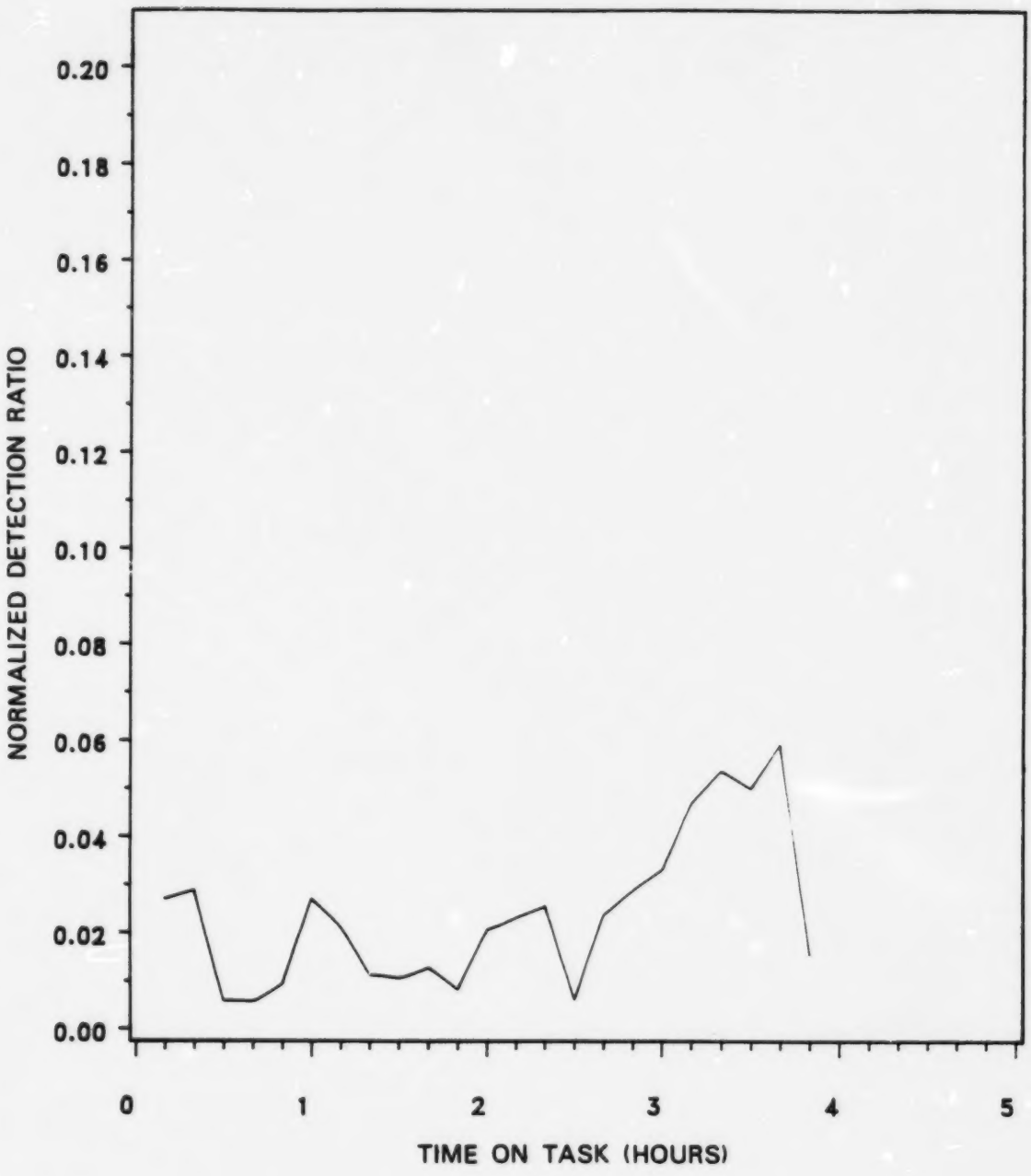


Figure 9 Average Normalized Detection Ratio as a Function of Time for Group 2

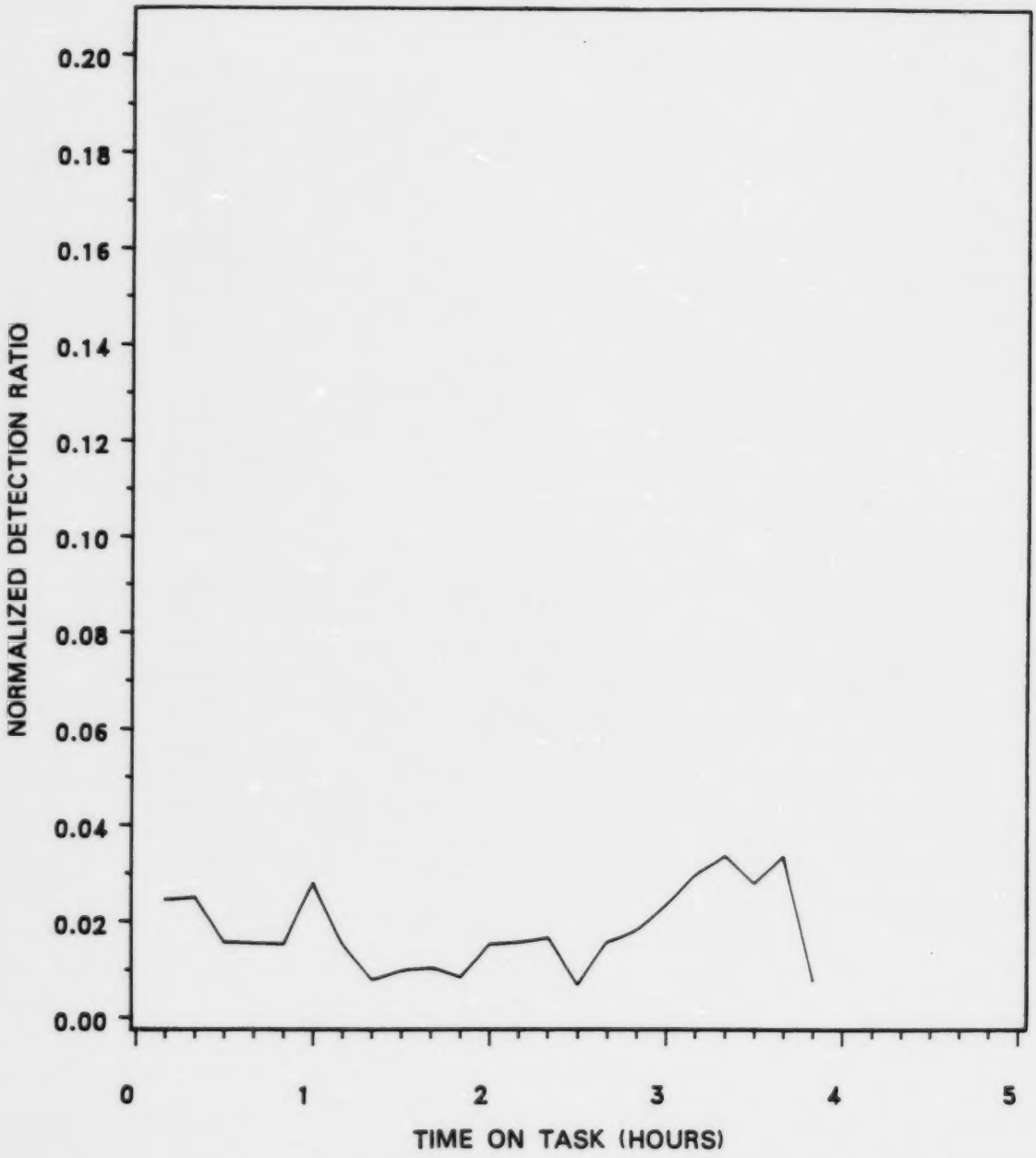


Figure 10 Average Normalized Detection Ratio as a Function of Time for Groups 1 and 2

in Group 2). Although, only slightly evident in Group 1, Group 2 (Figure 9) clearly showed a slight short lived improvement at about the 2 hour point when coffee was made available to the operators. Both groups showed a peak at about the 1 hour point.

5. DISCUSSION

5.1 Look Direction Selectivity

5.1.1 Direction

The tendency to detect more targets in the second quadrant might be explained by the clockwise rotation and the cueing effect of the heading marker. The time delay between the heading marker flash and the operator's response to the refreshed image may be such that full concentration may not occur until the second quadrant is being refreshed. By the time the operator had scanned the first and second quadrants and had started to look elsewhere to the third quadrant had been already refreshed, phosphor decay had started and full concentration was not achieved until the fourth quarter was being refreshed. Once the heading marker flashes again the cycle repeats itself. A greater concentration on the starboard side may also be related to the regulation regarding risk of collision in crossing situations wherein a vessel which has another vessel on their own starboard side shall keep out of the way of the other vessel.

During the first radar target detection experiment undertaken in Placentia Bay, Nefoundland (Dawe et al., 1986) it was found that all the detections occurred in the forward half of the radar and the majority occurred within the $\pm$ 45° of the ships heading. In the simulator experiment there were almost 11% more opportunities in the aft sector. Despite this, the percent detected in each sector is about equal. This supports the suggestion that radar operators tend to concentrate on the forward sector as indicated by the 1986 experiment. In the simulator experiments the operators knew they were not on board a real vessel, were not concerned about any potential hazards, and were more concerned about detecting targets. Had the situation been more realistic it is quite possible that there would have been an even greater bias towards the forward half of the PPI display.

5.1.2 Range

This detection data suggested that more targets were detected at the outer edge of the major clutter zone. United States Coast Guard (USCG) personnel have noted that past experiments indicated that during visual searches, lookouts tended to look along borders or edges (for example, along the side of a river, along the edge of a forest). This tendency might explain the phenomenon seen here. The significant number of targets seen inside the clutter zone is probably an artifact of the poor clutter simulation technique employed. NORDCO personnel did note this problem initially during visits to the simulator facility. In a real clutter situation there probably would have been relatively fewer detections made within the strong clutter zone.

5.2 Time Variability of Detection Success

No obvious explanation has been found for the inverse relationship between the number of opportunities and the percent detected. It might be speculated that the operator thought, after an initial period of time, that he was seeing false targets (too many were detected), thus a reduction in the percent detected occurred in the mid-range after and initial higher percent detection. After a 2 to 3 hour period a "pattern recognition effect" resulted in the operator being able to more definitely recognize true targets, giving a higher detection percentage toward the end of the search.

Another possibility is that the operator started the search at maximum alertness, resulting in more detections, tedium and fatigue then followed, resulting in lower detections. Finally, realizing that the search was coming to an end the operator began to work more diligently.

The normalized time on search trends seem to suggest some residual effects after removal of the "number of opportunities" bias. The overall slight drop in performance level after about an hour or so does give some indication, however small, that an operator should not be placed on radar watch for more than one hour. The slight and temporary improvement around the second hour correlates with the coffee break time and indicates that a longer break period is necesary for an operator's performance to return to the first hour level. The rise in performance in the latter period may be an artifact of the "eagerness" effect as alluded to above. The significance of the peak at one hour is unknown.

6. CONCLUSIONS

The simulator experiments showed a number of trends which have significance in terms a SAR operation using marine radar. The look direction selectivity suggests that, with current radar systems, some investigation is necessary in the need to utilize special search patterns to take into account the starboard side bias or some retraining of radar operators to remove it. The use of raster displays might remove some of this look direction bias. The tendency to detect more targets at the edge of the clutter also suggests that some retraining might be necessary for SAR operations.

The significance of the inverse relationship between the number of opportunities and percent detected is unknown in terms of its impact on a SAR operation. The number of opportunities was unrealistically large in terms of a real situation.

The time on search trend indicates that to maximize radar search performance radar operators should be relieved approximately every hour. A short coffee break is insufficient. The significance of the other trends are unknown.

Many of the trends indicated may have a lot to do with ergonomics and human physiology. In depth investigations of these factors are clearly beyond the scope of this experiment and require consultation with experts in these fields.

Finally, while an attempt will be made to investigate as many of these effects from the offshore experiment planned for autumn, 1988, it may be impossible to do so. This is because the number of opportunities and detections compiled in the simulator experiment are equivalent to that which could only be obtained from a great many real radar searches. The data set obtained from the size of the planned offshore experiment is likely to be insufficient for this purpose.

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APPENDIX C

CHRONOLOGY OF EVENTS

CHRONOLOGY OF EVENTS
OFFSHORE SEARCH AND RESCUE EXPERIMENT
CANSO BANK, 1987

1. DETAILED CHRONOLOGY OF THE OFFSHORE SAR EXPERIMENT

Tuesday, October 13 through Thursday, October 15, 1987

The CCGS "Sir William Alexander" was mobilized for the SAR experiment at the Coast Guard Base in Dartmouth, Nova Scotia. The navigation system receivers and computer, the Datawell wave measuring receiver and computer, and the printers were installed on a portion of the chart table on the bridge. System antennas were mounted on the hand rail surrounding the monkey's island immediately above the bridge. Humidity/temperature sensors contained within self-aspirating radiation shields were mounted outboard on the port and starboard sides of the ship just abaft and below the bridge at heights of 8.1 and 8.5 m, respectively. The remote digital display unit was mounted on the bridge adjacent to the navigation system.

Twenty life raft moorings systems provided by the CCG, 17 life rafts (4- and 6-man) from a variety of sources, and 20 life raft air supply systems were stowed aboard the ship.

Two LORAN-C buoys and a VHF receiver provided by the USCG, two LORAN-C buoy mooring systems, one Datawell wave measuring buoy and mooring system, and miscellaneous spares, hardware, and tools were also secured onboard ready for departure from Dartmouth on the evening of October 15, 1987. After topping up the fuel tanks, the CCGS "Sir William Alexander" departed Dartmouth for the Canso Bank at 2230 Atlantic Daylight Saving Time (ADT) Thursday evening, October 15, 1987 under the command of Captain William MacQuarrie. In addition to the officers and crew, 6 NORDCO Limited personnel and 2 USCG research scientists were aboard. Specifically, they were:

Mr. D. Bryant	NORDCO Limited
Mr. A. Fagan	NORDCO Limited
Mr. D. Finlayson	NORDCO Limited
Mr. W. Hunt	NORDCO Limited
Mr. J. Lundy	NORDCO Limited
Mr. W. Soper	NORDCO Limited
Dr. R.O. Robe	USCG R & D Center
Dr. A. Allen	USCG R & D Center.

Friday, October 16, 1987

In the early morning hours one of the ship's three main engines suffered catastrophic failure when the crank shaft broke. The Captain promptly decided to return to Dartmouth to have the damage assessed more fully and to obtain direction from CCG management regarding use of the ship for the project. The ship arrived back at the CCG Base about 1030 ADT. Inspection of the engine confirmed that no repair work could be done immediately, and, consequently, it was decided to proceed with the experiment as the ship still had two fully operational engines

capable of delivering more than ample power to the propulsion motors. While at the base, a minor problem relating to poor contacts on some of the boards in the wave data analysis and display computer was solved and a rented LORAN-C receiver was returned to the leasing agency because the receiver was unable to acquire time difference (TD) data from one of the three available TD's on the 5930 LORAN-C chain. The CCGS "Sir William Alexander" departed the CCG Base for Canso Bank at 1435 ADT.

Saturday, October 17, 1987

The ship arrived near the centre of Canso Bank about 0800 ADT. After a sounding survey, a LORAN-C buoy (USCG designation number 16) was deployed on a taut mooring system at position 45°06.7'N latitude, 60°23.4'W longitude, in a water depth of 66 m. The Datawell wave measuring buoy was then deployed on a 2:1 scope mooring in a position bearing 070° T, range 900 m (0.5 nautical miles (nmi)) from the LORAN-C buoy. Life raft moorings numbers 1 to 9 were deployed at various locations on the Canso Bank during the afternoon. For the initial radar detection tests the following targets were deployed:

1. a Mitsubishi Electric 400 milliampere MELSWEEP model H radar transponder was deployed at mooring number 01.

2. a Tul Manufacturing Limited 6-man canopied life raft was secured to mooring number 02.

3. a similar 6-man raft containing an omniazimuthal Luneburg lens type radar reflector (Lensref reflector manufactured by Tokyo Keiki Company Limited of Japan), having an equivalent radar cross section area of two square metres, was attached to mooring number 03; and,

4. a similar raft containing an air supply system was deployed at mooring number 04.

Maximum ranges of radar detection of the various targets were obtained in an overnight test. During the initial tests, the wind was from the southeast at 10 to 15 knots and the significant wave height was near 0.5 m.

Sunday, October 18, 1987

Mooring numbers 10 through 17 were deployed at random locations on the Canso Bank. By evening, a total of 10 life rafts had been deployed, all containing an air supply system and five having Lensref radar reflectors suspended just below the canopy top. Search 01 (visual and standard Sperry radar) was conducted overnight, the duration of the search was 8 hours. Moderate southerly winds veered to light northwesterly during the search. The significant wave heights were between 1.0 and 1.4 m. Visibility was generally good.

Monday, October 19, 1987

Certain improvements to the navigation system software were made during the early morning. Search 02 (visual, standard Sperry radar, and CAS radar) was conducted during daylight hours in significant wave heights between 1.7 and 1.9 m. The search duration was eight hours. Search 03 (visual, standard Sperry radar, and CAS unit) was conducted overnight, and lasted 10.5 hours. Moderate west-southwest winds, significant wave heights from 1.5 to 2.1 m., and good visibilities occurred during the search. Certain problems with the navigation system output were experienced during Search 03.

Tuesday, October 20, 1987

Servicing of a number of rafts was carried out during the day. This was required because certain rafts had become deflated. The problem was found to be most severe with the 6-man rafts and occurred because of air leakage at the inflation fitting. As no solution was immediately available, the air supply systems were removed from a number of the 6-man life rafts. Further modifications were made to the navigation system software during the day.

Search 04 (visual, standard Sperry, and CAS radars) was conducted from mid-afternoon to mid-evening. The duration of the search was 6 hours. Eight of the nine life rafts that had been deployed were recovered following search 04. The ship then proceeded to Mulgrave on the Strait of Canso.

Wednesday, October 21, 1987

The CCGS "Sir William Alexander" docked at Mulgrave at 0800 ADT. USCG personnel, Allen and Robe, and Bryant of NORDCO Limited departed for Halifax International Airport. The ship's crew change occurred at mid-day. Raft servicing was done in the afternoon. A status report was prepared and sent to the Rescue Coordination Centre (RCC), Halifax. The ship departed Mulgrave at 1730 ADT.

Thursday, October 22, 1987

The vessel arrived on the Canso Bank at first light. Mooring number 11, now considered to have been deployed too far from the centre of the experiment area, was recovered. Ten life rafts were then deployed on various moorings. Search 05 began at mid-afternoon and ended near midnight. A visual search was made throughout the nine hours while the radar searches, using the standard Sperry radar and CAS unit, were of 6 hours duration. Northwest winds from 25 to 43 knots, significant wave heights of 1.5 m increasing to 3.0 m, and good visibilities prevailed during the search.

Friday, October 23, 1987

Search 06, of five hours duration, was ended before sunrise. A visual lookout and standard and CAS radar watches were maintained throughout. Following the search, mooring number 14, which was also considered to be deployed too far from the centre of the experiment area, was recovered for re-deployment elsewhere. Search 07 (visual, standard Sperry and CAS radars) began at 1224 ADT and ended at 1850 ADT, shortly after civil twilight at 1832 ADT. The duration of the search was about 6.5 hours. In this search, the radar operators were provided free access to the chart showing target positions in order to determine maximum range of detection in significant wave heights between 1.5 to 2.0 m. No searches were conducted overnight because of the apparent futility of visually detecting the life rafts (the raft light batteries were weak) and by radar when significant wave heights were greater than about 1.5 m.

Saturday, October 24, 1987

Two life rafts were changed out for servicing. Search 08 (visual and standard Sperry marine radar) was started at 1018 ADT. As with Search 07, the radar operators were given access to life raft position information to further evaluate maximum ranges of detection. Visibility of more than 15 nmi, southwesterly winds of 25 to 30 knots, and significant wave heights of 1.2 to 1.5 m prevailed during Search 08. The search ended at 1616 ADT and was immediately followed by Search 09 (visual and standard Sperry radar). This search, made in conditions of southwesterly winds of 20 to 25 knots and significant wave heights of 1.4 m, ended after nightfall at 1845 ADT. The raft on Mooring 03, noted to have a collapsed canopy, was replaced following Search 09.

Sunday, October 25, 1987

Search 10 (visual, standard Sperry radar, and CAS radar) began at 0823 AST and ran for five hours. Search 11 (visual, standard Sperry radar, and CAS radar) was started at 1335 Atlantic Standard Time (AST) immediately upon completion of Search 10 and was ended at 1735 AST. The end time was near civil twilight when it became too dark to detect the life rafts since all light batteries had become very weak by this date. Southeast winds of 20 to 25 knots increased to 25 to 30 knots while the significant wave height increased from 1.1 m to 1.6 m during the day.

Following Search 11 the ship was taken alongside Mooring 03. The life raft that was secured to the mooring was fully inflated and contained a Lensref reflector suspended from the canopy tube. Radar detection tests were conducted using the standard Sperry radar as well as the CAS radar. Upwind, downwind, and across wind passes were made at various distances not exceeding 1.5 nmi (2.8 km). Despite the knowledge of the exact position of the targets, no detections were made using either of the radars. During the test, the winds were from the south-southeast at 25 to 30 knots and the significant height of the wind wave was 1.6 m; there was no swell evident.

Monday, October 26, 1987

Search 12 began at 0805 AST and ended at 1725 AST. Visual lookouts were maintained throughout the search. A radar search using the standard Sperry radar was terminated at 1112 AST. No radar detections had been made. During the radar search west-northwesterly winds of 25 to 30 knots and significant wave heights near 2 m prevailed.

Tuesday, October 27, 1987

Raft maintenance was carried out on 10 rafts with re-deployment at different moorings. Once again, five of the rafts contained Lensref radar reflectors. A visual examination of the LORAN-C buoy was then made; the buoy and mooring system appeared to be in good order. Search 13 was started at 1459 AST. The visual component was ended 1739 AST shortly after civil twilight. Radar searches using both the standard Sperry radar and the CAS radar ended at 1923 AST. During the search light westerly winds gradually backed to become light southeasterly and the significant wave height, due to a west-southwest swell only, was near 1.0 m throughout.

Search 14, an expanding square search pattern using the standard Sperry and CAS radars, began at 2019 AST and ended at midnight. There was little change in environmental conditions from those of the previous search.

Wednesday, October 28, 1987

Another radar search (Search 15) using both the standard Sperry and the CAS radar system was started shortly after Search 14 ended. The intention was to run the search until increasing sea clutter (resulting from an expected increase in a short period wind-wave) effectively eliminated all probability of detecting the targets. The search was conducted from 0053 AST until 0600 AST. During this period, the combined significant wave height remained between 0.9 and 1.0 m. However, the west-southwest swell diminished slightly as the wind-wave gradually developed.

Search 16, a visual search only, began at 0703 AST and ended at 1240 AST. Southeast winds near 20 knots at the beginning of the search gradually increased to 25 to 30 knots by the end. The significant wave height was near 1.0 m throughout the search. Visibility was estimated to be more than 15 nmi.

Search 17 (visual only) was started at 1308 AST and ended at 1725 AST. The winds during the search were southeasterly at 20 to 25 knots while the significant wave height increased from 1.2 to 1.5 m, the sea state composed of a wind-wave only. Visibility, which was greater than 15 nmi at the start of the search, was estimated to have decreased to 9 nmi by the end.

Thursday, October 29, 1987

Search 18 (visual only) was started at 0850 AST and ended at 1705 AST. The search was interrupted briefly at about 1435 AST to examine the status of the LORAN-C and wave measuring buoy. The buoys and mooring systems appeared to be in good order. The search resumed at 1458 AST. South-southeast gales of 35 to 40 knots at the beginning of the search veered and diminished to south-southwest 20 knots by the end, the significant wave height was between 2.7 and 3.1 m, and visibility was mainly less than 1.0 nmi in light rain, mist and fog. Upon completion of the search operations, the CCGS "Sir William Alexander" steamed to Mulgrave.

Friday, October 30, 1987

The ship remained at Mulgrave throughout the day to give all hands a break from the field work. Equipment on board the ship that was being used in the experiment was sorted and tidied up and some minor repairs were made to the life rafts. A project status report was prepared and sent to RCC Halifax. The ship departed Mulgrave in the early evening.

Saturday, October 31, 1987

The CCGS "Sir William Alexander" arrived on the Canso Bank at first light. Search 19 (a visual search only) began at 0711 AST and ended at 1245 AST. Southerly winds of 20 to 25 knots increased to near gale force early in the search but veered to southwesterly 15 knots by the end. The significant wave height of the combined sea and swell ranged between 1.5 and 1.8 m. Twelve nautical mile visibility at the onset of the search lowered to 6 nmi in rain showers and mist toward the end of the search.

During the afternoon, the LORAN-C buoy and all 10 moored life rafts were recovered. Winds had backed from south-southwest at 15 knots to north-northeast 25 knots shortly before sunset. The final two rafts were recovered in northwest gales and building seas having a significant wave height of 2.3 m. The ship departed the Canso Bank for Dartmouth at 1930 AST.

Sunday, November 01, 1987

The CCGS "Sir William Alexander" arrived at the CCG Base, Dartmouth, at 0800 AST. NORDCO employees, Fagan and Soper, departed for St. John's, Newfoundland. The field equipment was serviced, life rafts requiring professional repair were separated, and the LORAN-C buoy TD data stored in RAM was downloaded to a floppy disk using the Compaq microcomputer.

Mr. B. Dawe and R. Tucker of NORDCO Limited and Mr. R. Wetmore of Raytheon Marine Company in Hudson, New Hampshire, arrived in Dartmouth.

Monday, November 02, 1987 to Thursday, November 05, 1987

The CCGS "Sir William Alexander" remained at the CCG Base in Dartmouth while the Raytheon Pathfinder ST marine radar system was installed aboard the ship. The transceiver unit with a 2.3 m antenna was mounted on a steel pedestal welded to the monkey's island at a height of 17.9 m above the design water line. The radar signal processing unit and raster scan display were installed in the ship's electronics room on the boat deck. The installation of the system was done under the supervision of R. Wetmore.

During the time in port, six life rafts were sent out for repairs at local servicing facilities. The rafts were returned to the ship on November 05, 1987.

The CCGS "Sir William Alexander" departed for the Canso Bank at 2030 AST on Thursday, November 05, 1987 under the command of Captain J.F. McKenna. In addition to the ship's officers and crew, the following individuals were on board:

Mr. D. Bryant - NORDCO Limited
Mr. B. Dawe - NORDCO Limited
Mr. D. Finlayson - NORDCO Limited
Mr. R. Soper - NORDCO Limited
Mr. R. Tucker - NORDCO Limited
Mr. Wm. Reynolds - USCG
Mr. L. Luendoski - USCG
Mr. R. Wetmore - Raytheon Marine Company
Mr. P. Redis - Raytheon Marine Company.

Friday, November 06, 1987

The ship arrived on the Canso Bank shortly after sunrise, however, strong west-northwest winds of 25 to 30 knots and significant wave heights estimated at 2.0 m precluded deployment of the LORAN-C buoy and search targets. The ship then proceeded to Chedabucto Bay in order to conduct a further radar detection test in the sheltered waters. A spar buoy having a 2 square metre radar cross section Lensref reflector mounted 1.1 m above the sea surface was moored in position 45°24.9'N, 61°11.12'W. The Sperry CAS radar and the Raytheon Pathfinder ST radar were used to determine the maximum ranges of detection. Westerly winds at 18 knots at the beginning of the test (1325 AST) veered to northwest winds at 10 knots by the end (1550 AST). The significant wave height was near 0.3 m throughout the test.

Saturday, November 07, 1987

The CCGS "Sir William Alexander" arrived on the Canso Bank at about 0800 AST. Westerly gales of 35 to 40 knots and significant wave heights of 3.4 m prevented deployment of the LORAN-C buoy, spar buoys, and life rafts. The ship then proceeded to Mulgrave.

Sunday, November 08, 1987

Mr. P. Redis of Raytheon departed the ship. High winds and seas continued to prevent work on the Canso Bank. Another radar detection test was conducted in Chedabucto Bay. Once again, the Sperry CAS and Raytheon Pathfinder systems were used. The target in this instance was a 4-man life raft containing a Lensref reflector suspended just below the canopy tube. The winds were west to southwest 25 to 30 knots and the significant wave height, due to a wind-wave only, was estimated at 1.0 m during the test. The ship anchored in Chedabucto Bay overnight.

Monday, November 09, 1987

The CCGS "Sir William Alexander" arrived on the Canso Bank about 0800 AST. Nine life rafts, 4 Lensref radar reflectors, and one radar transponder were deployed at 12 target moorings. The radar reflectors were mounted on spar buoys 1.1 m above the water surface.

Search 20 (visual, standard Sperry radar, and Raytheon radar) was started at 1742 AST, well after sunset, and ended at 2332 AST. Two sets of night vision goggles were used by the USCG representatives. During the search winds were generally from the west-southwest at 20 to 25 knots and the significant wave height, due to a wind-wave only, was 1.8 to 2.1 m. Visibility was estimated to be 4 to 6 nmi in mist and light rain showers. The ship remained on the Canso Bank overnight, although no further searches were conducted.

Tuesday, November 10, 1987

LORAN-C buoy (#13) was powered up and reset at 0800 AST, then deployed on the original LORAN-C buoy mooring at 0930 AST. The unit appeared to be functioning normally. Search 21 (visual, standard Sperry radar, and Raytheon radar searches) began at 1100 AST and ended at 1700 AST. The winds were generally light northwesterly, the significant wave height was near 1.3 m, and the visibility was 12 to 15 nmi. There were some light rain showers during the first 2 hours of the search.

Search 22 (visual, standard Sperry radar, and Raytheon radar) began after dark at 1800 AST and was ended at 2347 AST. Night vision goggles were used by the 2 visual lookouts and the USCG representatives. Northwest winds of 15 knots, significant wave heights of very near 1.0 m, and 15 nmi visibility prevailed during the search. Following the search, the ship remained in the Canso Bank area overnight.

Wednesday, November 11, 1987

Search 23 was started at 0835 AST (visual, standard Sperry radar, and Raytheon system) and ended at 1120 AST. Northeasterly winds 20 to 25 knots with significant wave heights near 1.5 m and visibilities ranging from 5 to 8 nmi prevailed during the search.

Following the search all 9 life rafts were recovered in order to avoid damage in the heavy winds and seas that were expected to develop as a gale centre passed across the Scotian Shelf on Thursday. The ship then steamed to Mulgrave where it was docked at 1945 AST.

Thursday, November 12, 1987

Mr. R. Fitzgerald of NORDCO Limited arrived aboard at 0800 AST to replace Mr. B. Dawe who departed with W. Reynolds, L. Luendoski, and R. Wetmore at about 0900 AST.

The CCGS "Sir William Alexander" remained at Mulgrave throughout the day. Southeast winds of gale force during the morning hours diminished to light variable winds in the afternoon, then increased to strong northwest gales overnight.

Friday, November 13, 1987

The ship remained at Mulgrave throughout the day awaiting arrival of a technician to service one of the ship's main propulsion circuit breaker units. Strong northwest gales during the morning hours gradually diminished in the afternoon.

Saturday, November 14, 1987

The ship departed Mulgrave at 0800 AST for the Canso Bank. At 0930 AST, the Captain turned the ship back to Mulgrave in order that an ill member of the crew could receive medical attention. Since the ship would not be able to return to the Canso Bank until near dusk and little useful work could be accomplished, it was decided to delay departure from Mulgrave until early Sunday morning.

Sunday, November 15, 1987

The ship arrived on the Canso Bank at 0745 AST. Nine life rafts and one spar buoy with a Lensref reflector were deployed during the morning and early afternoon. All the life rafts were equipped with fresh batteries. Two moorings were not located and were presumed to have been lost in the heavy weather of the preceding days.

Search 24 (visual, standard Sperry radar, and Raytheon radar) began at 1535 AST and ended at 2232 AST. Northwest winds of 30 to 40 knot gales, significant wave heights of 2.1 to 2.5 m, and good visibilities prevailed during the search. Search 25 (visual search only) was conducted overnight beginning at 2250 AST and ending at 0541 AST. Northwest winds near 25 knots increased to 34 to 40 knot gales during the search. The significant wave heights were between 1.9 and 2.3 m. Visibility was good throughout.

Search 26 (visual, standard Sperry radar, and Raytheon radar) began at 0801 AST and ended at 1421 AST. Search 27, a short electronic search using both the standard Sperry radar and the Raytheon unit began

at 1436 AST and ended at 1719 AST. There was little change in the environmental conditions during Searches 26 and 27 from those experienced during Search 25.

Search 28, a night-time visual search only, began at 1824 AST and ended at 0145 AST. Winds were generally 20 to 27 knots from the northwest, significant wave heights ranged between 1.4 and 2.2 m, and visibility remained good during the search. No further searches were conducted overnight since it had been concluded that the life raft light batteries had weakened markedly since their deployment.

Tuesday, November 17, 1987

The morning and early afternoon were spent servicing the life rafts. None of the life rafts were illuminated and unfortunately, no additional batteries were available as replacements. One life raft, identified as Number 13, had come adrift from its mooring and was lost.

Search 29 (visual, standard Sperry radar, and Raytheon system) began at 1442 AST. The visual component of the search ended at 1700 AST, very near civil twilight, when it became too dark to continue. The radar searches continued until 2323 AST. West-southwest to southwest winds near 20 knots, significant wave heights 0.6 to 1.1 m, and good visibility prevailed during Search 29. No further searching was conducted overnight and the ship remained in the Canso Bank area.

Wednesday, November 19, 1987

Search 30 was to begin at 0700 AST as a visual search. However, with visibility between 1/8 and 1/4 nmi in fog, the start time was delayed. The radar search component using both the standard Sperry and the Raytheon radars began at 0805 AST. With improving visibility, the visual search began at 0920 AST. At 1317 AST the search was temporarily halted to examine the LORAN-C buoy as no positional data had been received for some time. The unit's antenna and antenna base were noted to be missing. While winds were only of moderate strength, the significant wave height was near 2 m, due primarily to a south-southwest swell. Consequently, it was decided not to attempt a recovery of the buoy. The search pattern was resumed at 1337 AST; however, the search was ended a few minutes later as the 5930 LORAN-C chain was shut down for approximately one hour following a pre-announced service schedule.

Search 31 (visual, standard Sperry radar, and Raytheon radar) began at 1537 AST. The visual component ended at 1700 AST while the radar component continued until 2000 AST. Winds were generally light and variable in direction during Search 31. The significant wave height, which was due almost entirely to a south-southwest swell, was observed to be between 1.7 and 2.2 m. The visibility was good throughout the search.

Friday, November 20, 1987

Search 32 (visual, standard Sperry radar, and Raytheon radar) began at 0723 AST and ended at 1158 AST. During this search the winds were out of the southeast at 17 to 24 knots, significant wave heights were near 1.7 m, and visibility was good.

In expectation of heavy winds and high seas associated with a developing storm system, life raft recovery operations commenced at about 1215 AST and were complete just before sunset. During the recovery, a message was received indicating that the ship would be required for SAR duty off the western shore of Nova Scotia at the beginning of December. Since certain fuel tank maintenance would be required prior to this work, it would be necessary to terminate the project a few days earlier than originally planned.

Storm force east-southeast winds developed in the early evening while the ship was steaming toward Chedabucto Bay. The vessel was anchored in the Bay overnight.

Saturday, November 21, 1987

The CCGS "Sir William Alexander" was moved from Chedabucto Bay to a wharf near the Canso Causeway waiting on weather to proceed with the experiment offshore.

Sunday, November 22, 1987

The ship departed at 0900 AST to examine sea conditions offshore. A swell estimated at 4 to 5 m precluded any possibility of recovering the target moorings on the Canso Bank. The ship was anchored in Chedabucto Bay overnight.

Monday, November 23, 1987

The CCGS "Sir William Alexander" was underway at 0500 AST to begin mooring recovery operations. Ten target moorings were recovered; 3 of them were spar buoys with Lensref reflectors. Three moorings could not be located and were presumed to have broken free during the weekend storm. One Lensref reflector was lost. West-southwest winds of 25 to 30 knots and 2.7 to 3.0 m significant wave heights prevailed during the recovery operations.

The LORAN-C buoy was examined and found to be submerged. Sea conditions prevented recovery of the buoy. At dusk, a course was laid for Chedabucto Bay where the ship remained overnight.

Tuesday, November 24, 1987

Recovery of the wave measuring buoy began at 0715 AST using the ship's workboat. The buoy was recovered without incident and was onboard the ship at 0815 AST. The LORAN-C buoy and surface float were

then recovered and, as suspected, the buoy was found to be filled with sea water. Chafing of the mooring line on the ship's rail resulted in the loss of the submerged float and the anchor weights. Of the three remaining target moorings, one was recovered successfully while the other two could not be located and were presumed to be lost.

A moderate southwest wind and a 1.5 m swell prevailed during the day. The ship departed the Canso Bank at 1305 AST bound for the CCG Base at Dartmouth.

Wednesday, November 25, 1987

The CCGS "Sir William Alexander" was docked at the Base about 1100 AST. With the exception of the Raytheon Pathfinder ST Radar system, all the equipment was demobilized, packed, and secured in a rental truck for transport to St. John's, Newfoundland. Mr. R. Fitzgerald and Mr. R. Soper, who drove the truck, departed Dartmouth at about 1700 AST. Mr. D. Bryant and Mr. D. Finlayson left for St. John's by air in the evening.

Thursday, November 26, 1987

The Raytheon radar system was removed from the ship and packed for shipment back to the manufacturer's facilities under the supervision of Mr. R. Tucker. Mr. Tucker departed for St. John's by air in the evening.

APPENDIX D

SUMMARY OF ENVIRONMENTAL CONDITIONS

ENVIRONMENTAL CONDITIONS

DAYTIME VISUAL SEARCHES

#	VISIBILITY (nmi)	WIND (T, kt)	HS (m)	NOTES
2	15+	NW 10	1.7-1.9	MAINLY SE SWELL
4	15	SWLY 10	1.0-1.3	MAINLY SE SWELL
5	8 INCR 15	NW 25-43	1.5 INCR 2.7-3.0	WIND-WAVE ONLY
7	15+	WNW 15-20	1.0 INCR 1.5-1.7	
8	15+	SWLY 25-30	1.2 INCR 1.4	WIND-WAVE ONLY
9	15 BCMG 12	SWLY 20	1.4	WIND-WAVE ONLY
10	15+	SSE 20-28	1.1 INCR 1.4	
11	15	SE 23-[illegible]	1.4-1.6	WIND-WAVE ONLY
12	15+	NWLY 22-30	1.9-2.3	1.3-1.8m WIND WAVE + SELY SWELL
13	15+	LGT & VRBL	0.9-1.0	WSW SWELL ONLY
16	15+	SELY 18-28	0.9-1.1	WIND-WAVE ONLY
17	15+ BCMG 9	SELY 17-25	1.2 INCR 1.5	WIND-WAVE ONLY
18	2 BCMG 1/8	SSE 40 VRG SLY 20-25	2.3 INCR 3.0	WIND-WAVE ONLY
19	12 BCMG 5	SLY 25-30 BCMG SW15	1.6-1.8	
21	12 INCR 15	NNWLY 6-12	1.2-1.4	MAINLY SWLY SWELL
23	8 BCMG 5	NE 20-25	1.5	WIND-WAVE ONLY
26	15	NWLY 25-36	2.0-2.2	WIND-WAVE ONLY
29	15	WLY 15 BCMG SW 15-20	0.6 INCR 1.0	WIND-WAVE ONLY
30	1/8 INCR 15+	WSW 15 VRG WNW 15	2.2 - 2.4	MAINLY SSW SWELL
31	15	LGT & VRBL	1.8-2.1	MAINLY SSW SWELL
32	15+	SE 17-24	1.5-1.8	MAINLY SSW SWELL

NIGHT-TIME VISUAL SEARCHES (LIGHTS ON RAFTS)

#	VISIBILITY (nmi)	WIND (T, kt)	HS (m)	NOTES
1	15+ BCMG 5	SSE 20 VRG NWLY 8	1.0 INCR 1.4	MAINLY WIND-WAVE
3	10 BCMG 15	SW-W 15	2.0 BCMG 1.5	
24	12 BCMG 15	NNW 32-40	2.5 BCMG 2.3	WIND-WAVE ONLY
25	15	NWLY 25-40	2.2 BCMG 1.9	WIND-WAVE ONLY

NIGHT VISION SYSTEMS SEARCHES

#	VISIBILITY (nmi)	WIND (T, kt)	HS (m)	NOTES
20	4-6	SW 25-30 VRG NW 25	1.8-2.0	WIND-WAVE ONLY
22	15	NW 10 BCMG 20	0.9-1.1	MAINLY SW SWELL

ENVIRONMENTAL CONDITIONS

STANDARD SPERRY RADAR SEARCHES

#	WINDS (T, kt)	Hs (m)	NOTES
1	SSE 20 VRG NWLY 8	1.0 INCR 1.4	MAINLY WIND-WAVE, BRIEF RW--
2	NW 10	1.7-1.9	MAINLY SE SWELL
3	SW-W 15	2.0 BCMG 1.5	
4	SWLY 10	1.0-1.3	MAINLY SE SWELL
5	NW 25-43	1.5 INCR 2.7-3.0	WIND-WAVE ONLY, 2 h R--
6	WNWLY 30	2.4 - 2.8	
7	WNW 15-20	1.0 INCR 1.5-1.7	
8	SWLY 25-30	1.2 INCR 1.4	WIND-WAVE ONLY
9	SWLY 20	1.4	WIND-WAVE ONLY, BRIEF RW-
10	SSE 20-28	1.1 INCR 1.4	
11	SE 23-30	1.4-1.6	WIND-WAVE ONLY
12	NWLY 22-30	1.9-2.3	1.3-1.8m WIND-WAVE + SELY SWELL
13	LGT & VRBL	0.9-1.0	WSW SWELL ONLY
14	S-SW 8-12	0.9	WSW SWELL ONLY
15	S 10 BCKG SE 15-20	0.9-1.0	MAINLY WSW SWELL
20	SW 25-30 VRG NW 25	1.8-2.0	0.3 h RW-
21	NNWLY 6-12	1.2-1.4	MAINLY SWLY SWELL, 2.5 h RW-, R--
22	NW 10 BCMG 20	0.9-1.1	MAINLY SW SWELL, 0.3 h SW-
23	NE 20-25	1.5	WIND-WAVE ONLY, R-THROUGHOUT
24	NNW 32-40	2.5 BCMG 2.3	WIND-WAVE ONLY
26	NWLY 25-36	2.0-2.2	WIND-WAVE ONLY, 2-3 h SW-
27	NW 28-37	2.3 BCMG 2.1	WIND-WAVE ONLY
29	WLY 15 BCMG SW 15-20	0.6 INCR 1.0	WIND-WAVE ONLY
30	WSW 15 VRG WNW 15	2.2-2.4	MAINLY SSW SWELL
31	LGT & VRBL	1.8-2.1	MAINLY SSW SWELL
32	SE 17-24	1.5-1.8	MAINLY SSW SWELL

CAS SPERRY RADAR SEARCHES

#	WINDS (T, kt)	HS (m)	NOTES
2	NW10	1.7-1.9	MAINLY SE SWELL
3	SW - W 15	2.0 BCMG 1.5	
4	SWLY 10	1.0-1.3	MAINLY SE SWELL
5	NW25-43	1.5 INCR. 2.7-3.0	WIND WAVE ONLY, 2 h R--
6	WN WLY 30	2.4-2.8	
7	WNW 15-20	1.0 INCR. 1.5-1.7	
10	SSE 20-28	1.1 INCR. 1.4	
11	SE 23-30	1.4-1.6	WIND WAVE ONLY
13	LGT & VRBL	0.9-1.0	WSW SWELL ONLY
14	S-SW 8-12	0.9	WSW SWELL ONLY
15	S 10 BCKG SE 15-20	0.9-1.0	MAINLY WSW SWELL

ENVIRONMENTAL CONDITIONS (CONT'D)

RAYTHEON PATHFINDER ST RADAR SEARCHES

#	WIND (T, kt)	Hs (m)	NOTES
20	SW 25-30 VRG NW25	1.8-2.0	0.3 h RW-
21	NNWLY 6-12	1.2-1.4	MAINLY SWLY SWELL, 2.5 h L--, RW-, R--
22	NW 10 BCMG 20	0.9-1.1	MAINLY SW SWELL, 0.3 h SW-
23	NE 20-25	1.5	WIND-WAVE ONLY, R- THROUGHOUT
24	NNW 32-40	2.5 BCMG 2.3	WIND-WAVE ONLY
26	NWLY 25-36	2.0-2.2	WIND-WAVE ONLY, 2-3 h SW-
27	NW 28-37	2.3 BCMG 2.1	WIND-WAVE ONLY
29	WLY 15 BCMG SW 15-20	0.6 INCR. 1.0	WIND-WAVE ONLY
30	WSW 15 VRG WNW 15	2.2-2.4	MAINLY SSW SWELL
31	LGT & VRBL	1.8-2.1	MAINLY SSW SWELL
32	SE 17-24	1.5-1.8	MAINLY SSW SWELL

APPENDIX E

LENSREF REFLECTOR
BROCHURE

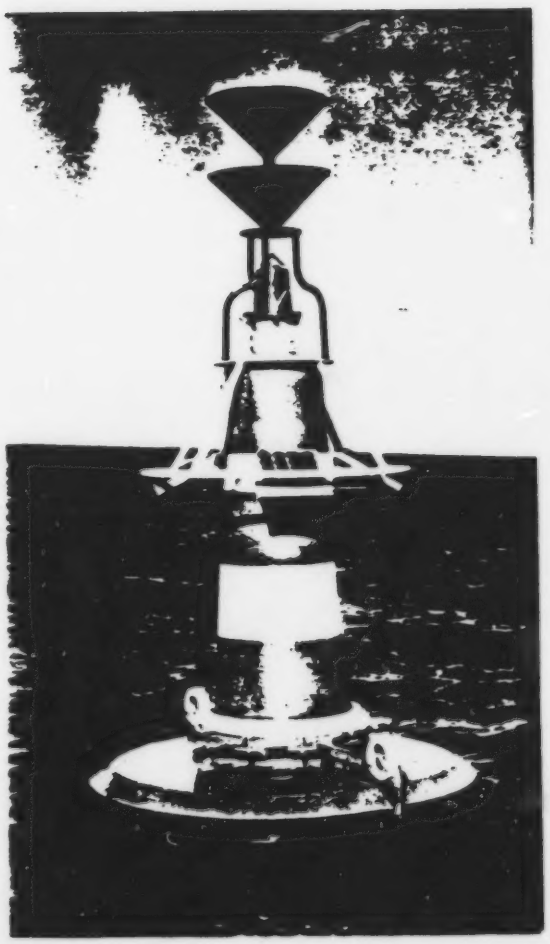
APPLICATIONS

One of the most frequent applications for LENSREF radar reflectors is their use as navigation aids installed upon piers, buoys, boats, and ships. They have been highly effective in enhancing the radar image of these nautical objects, thus rendering them more conspicuous. For example, certain types of wooden and fiberglass boats produce very faint images on a radar screen. The use of a 12 inch diameter omniazimuth reflector, when viewed from any horizontal direction, will provide a 10 square meter equivalent radar cross section (RCS) target, producing a radar image similar to that of a forty-ton steel trawler. This is many times the reflectance of a corner reflector array of equal size and is, of course, much more uniformly conspicuous in all horizontal directions. (Corner reflectors are characterized by "holidays" or "dead spots" in their reflective patterns.)

In some installations, arrays of the lenses have been used to create a characteristic, recognizable pattern.

Other applications include use in military targets, installation on markers for towed sonar arrays, monitoring of ice floes and precise marking of points on terrain (instrumented ranges).

The observed performance of the 8 inch and 12 inch omniazimuth marine models is shown in the table below.



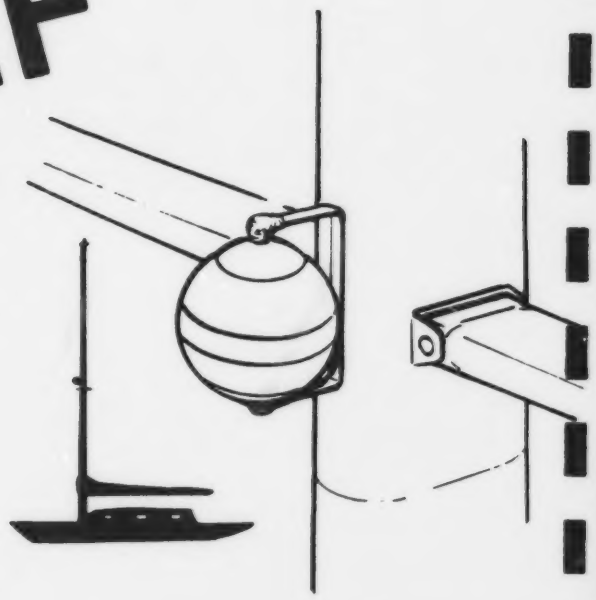
Lens Diameter (mm)	Lens Diameter (inches)	Radar* Antenna Height** (meters)	Lens Height** (meters)	Range, Calm Sea (miles)	Range, Rough Sea (miles)
305	12	7	2	5½–6	4–5
305	12	7	5	7–8	5–5½
305	12	15	5	10+	
203	8	7	2	4–4½	3–3½
203	8	7	5	5–5½	4–4½
203	8	15	5	7+	

* Radar: X-Band, 3cm, 10 kw peak power

** Above sea surface

LENSREF®

DIELECTRIC LENS MICROWAVE RADAR REFLECTOR



highest detection reliability

unmatched range performance

DESCRIPTION

A Luneberg lens radar reflector, such as the LENSREF, returns to the interrogating radar antenna very nearly the maximum amount of signal that possibly can be returned by any object of equivalent size. Properly mounted omniazimuth models of LENSREF have almost the performance of pure Luneberg lenses, but offer, also, the advantage of a uniform pattern of reflectance in all azimuth directions. They are much more reliable reflectors than masts, spars, rigging and, of course, octahedronal (corner) reflectors. Even in rough seas, LENSREFS are visible clearly on radar at ranges of 8,000 yards or more. The 8-inch LENSREF has been mistaken for a large, steel vessel (one viewer claimed it was a DD) at ranges up to 27,000 yards.

LENSREFS for marine markets are available from stock in two basic sizes: 8-inch diameter and 12-inch diameter. The 8-inch one, weighing 5.5 pounds, is equipped with a vertical axial rod so that it either can be hung from rigging or can be permanently mounted on a mast with brackets. The 12-inch unit, weighing 14.4 pounds, is equipped with a pedestal base for mounting onto a horizontal surface such as the overhead of a wheelhouse.

DESCRIPTION

LENSREF is a radar version of the scientifically recognized Luneberg lens. It is used to enhance the radar visibility of a target upon which it is installed. For example, a buoy with a LENSREF upon it might appear on a radar screen as brightly as a ship, or a drone might appear as large as an airplane.

The LENSREF reflector is spherical, consisting of a number of concentric spherical dielectric shells. Each shell has a different index of refraction, so that an entering signal will be refracted into a nearly elliptical path to a point on the opposite surface of the sphere (Figure 1). A reflective material located at this opposition point causes a return of the signal, again refracted elliptically through the sphere and out again in the direction from which it came.

LENSREF performs much as a parabolic reflector, except that whereas a parabolic reflector is effective only along its central axis (PX), the LENSREF is an effective retroreflector over a wide range of entry angles (such as P'X' to P"X" in Figure 1, for example). The performance in this respect is limited only by the practical limitations of the reflector geometry. The result is a completely passive, reflective device, which concentrates the reflected energy back in the direction of the incident beam.

Some LENSREF lenses are built with "skull cap" reflectors, as shown in Figure 2, indicated by the letter M. Normally these will have a conical reflective pattern, with the pattern cone subtending 120° at the 3 dB points. Narrower conical patterns can be achieved by reducing the sizes of the reflector surfaces.

Another configuration calls for the use of a circumferential-band reflector ("belt") as shown in Figure 3. This reflector is omnidirectional in the horizontal plane. The pattern is uniform in all directions within that plane and for an angle of about 18° above and below horizontal. The belt shades a large, central portion of the sphere, so the equivalent radar cross section (RCS) of such a lens is only about one-third that of a conical pattern lens of the same diameter.

LENSREFs are designed to be optimum for use with X-Band radar, but they are broad-band devices and also provide useful performance at other radar frequencies.

Some LENSREFs are manufactured to satisfy stringent military specifications for use in military, naval, aeronautical, and other rigorous applications. Others are manufactured specifically for the marine environment and are provided with means for mounting them upon buoys, navigational aids, boats, ships or bridges. The lenses are available in a wide range of sizes from 4 inches to 26 inches in diameter, with equivalent radar cross sections from 0.75 to 350 square meters in X-Band.

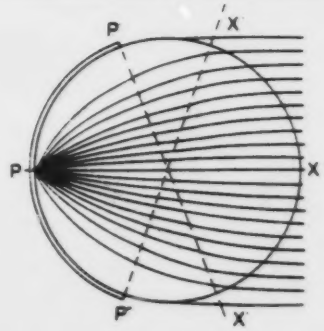


Fig.1—Signal Path in the Luneberg Lens

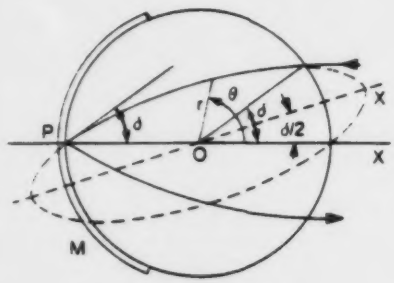


Fig.2—Elliptical Path in the Luneberg Lens

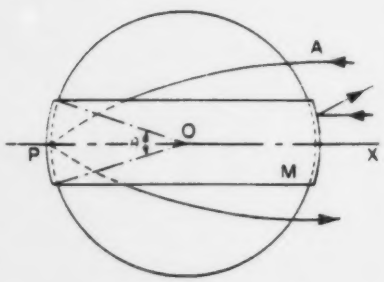


Fig.3—Construction and theory of the omniazimuth radar reflector

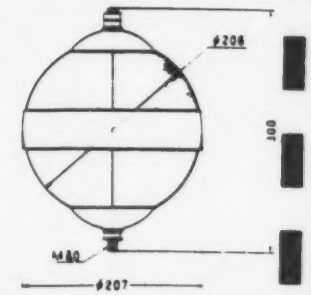
TECHNICAL SPECIFICATIONS

Model	Diameter * (mm)	(inches approx.)	Pattern	Equivalent RCS **	Weight (kg)	(lbs.)
DL-414	102	4	Conical	0.7	0.22	0.5
DL-436	102	4	Omniazimuth	0.14	0.22	0.5
DL-614	152	6	Conical	3.0		
DL-714	178	7	Conical	4.8	1.3	2.9
DL-8A	203	8	Omniazimuth	2.0	2.5	5.5
DL-814	203	8	Conical	6.5	2.5	5.5
DL-12A	305	12	Omniazimuth	10.0	6.5	14.4
DL-12	305	12	Conical	30.0	6.5	14.4
DL-2290	559	22	Conical	160.0	50.0	110
DL-26A	660	26	Omniazimuth	100.0	60.0	133
DL-26	660	26	Conical	350.0	60.0	133

* Diameter of dielectric materials, not including outer cover.

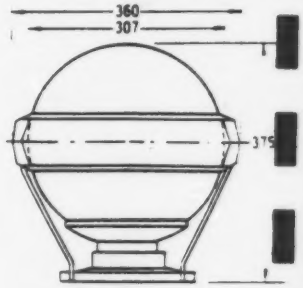
** RCS: Square meters — X-band (3cm) radar — RCS at center of conical patterns, or minimum RCS in center plane normal to reflector belt ("horizontal plane") of omniazimuth units — polarization immaterial.

MODEL DL-8A

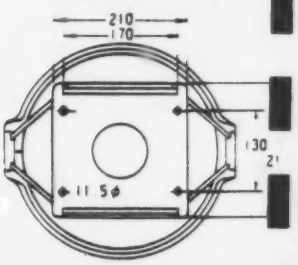


MODEL DL-12A

ELEVATION



BOTTOM VIEW



Dimensions in millimeters

PATENTS:

U.S.A.: 3465362, 3860927
U.K.: 1117885
JAPAN: 436915, 462851, 544316, 594197
OTHERS: Pending

VARIGAS INTERNATIONAL, INC.

P.O.BOX 445
LUTHERVILLE, MARYLAND, 21093
PHONE: (301) 252-3026 CABLE: VARIGAS, BALTIMORE, MARYLAND

MARITIME FACILITIES CO., LTD.

31, Nishi-Gotanda 1-chome, Shinagawa-ku, Tokyo 141, JAPAN
Tel. (03) 490-5278, 5279 cable Address: MAFCOTOK
Telex No.: C/O 0246-6193 TOKEITJ

MAXIMUM REFLECTIVITY

LENSREF is a Luneberg lens. It returns to the interrogating radar a large portion of the energy falling upon it by concentrating and projecting that energy back into the direction of the interrogating radar. Such a configuration provides absolutely the highest reflectivity per unit size of any reflector type.

UNIFORM REFLECTIVITY

When properly mounted, the LENSREF reflects the same amount of energy when interrogated from all azimuth directions and hence has uniformly the same radar appearance from all azimuth directions (unlike corner reflectors which reflect effectively only from certain selected angles).

STREAMLINED

The clean, spherical surface of LENSREF provides the least wind resistance of all reflector types.

SMOOTH

Minimum or no chafing of rigging will occur from a properly mounted LENSREF. The glossy, round surface of LENSREF is easy on sails and lines.

DURABILITY

The weatherproof outer cover of polyurethane should provide many years of life, yielding top quality performance at all times (corner reflectors, if bent even slightly from perfect right angles, exhibit drastically reduced performance).

PASSIVE

The superior performance of LENSREF is achieved without the need for any electric power. Simply mount it in the proper position and forget it; however, do not paint it.

For top performance and maximum safety at sea, install the very best radar reflector that money can buy. It costs more, but it's worth it.

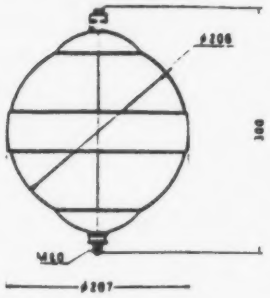
ORDERING INSTRUCTIONS

The 8-inch diameter spherical LENSREF with polar axial threaded rod, for suspension in rigging or fixing to a mast, is the unit most popular among owners of sailing yachts. It is Model DL-8A.

The 12-inch diameter spherical LENSREF, with pedestal mount, is most often used on power vessels. It is Model DL-12A.

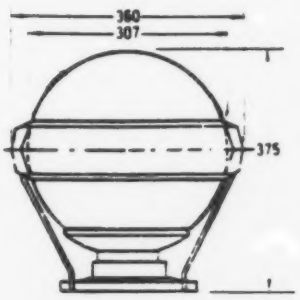
Both the DL-8A and DL-12A normally are available from stock. Other sizes and models having other reflective patterns are available by special order.

MODEL DL-8A

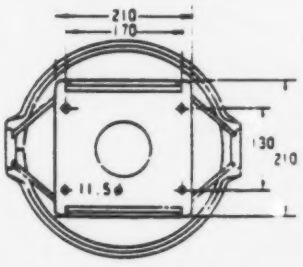


MODEL DL-12A

ELEVATION



BOTTOM VIEW



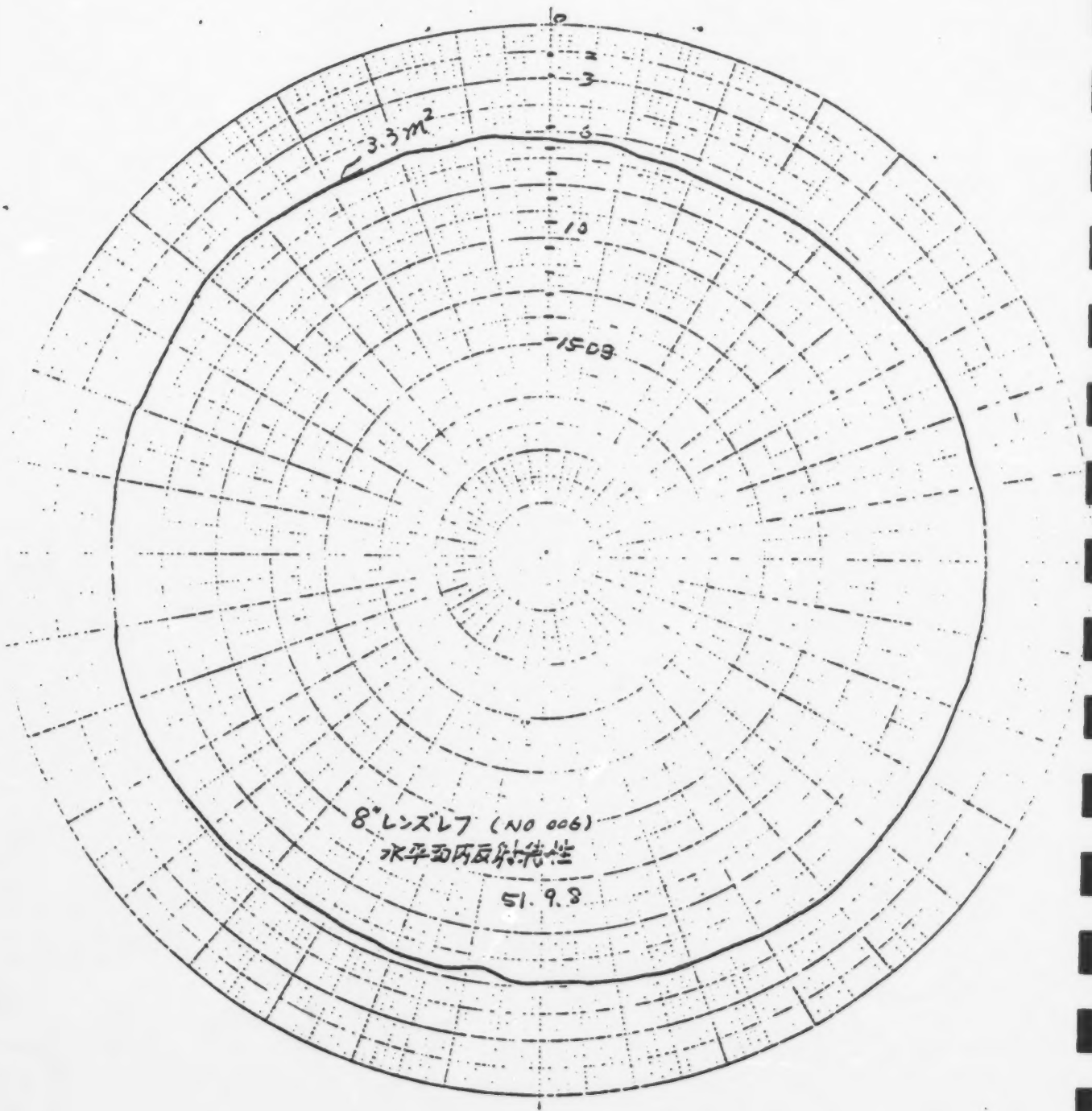
Dimensions in millimeters

DEALER INQUIRIES INVITED

LENSREF may be ordered from your dealer or directly from **VARIGAS INTERNATIONAL INC.**
P.O. BOX 445 - TIMONIUM, MARYLAND 21093
(301) 252-3026

VRI 1082 © VARIGAS 1982

DL-8A Lensref reflective pattern (Horizontal) LENSREF 8" Model



APPENDIX G

DETAILED SPECIFICATIONS OF THE RADAR SYSTEMS

1 SPERRY MK 4016X RADAR (STANDARD SPERRY)

1.1 Processing and Display Unit

- MK 4016X 16 inch (40 cm) PPI display.
- Mechanical Cursor
- Fixed and Movable double azimuth ring (gyro stabilized azimuth ring adaptor).
- Flat face reflector plotter
- Range:
  - Scale: .25, .50, 1.5, 3.0, 6.0, 12.0, 24.0, 120 nmi.
  - Rings interval: .125, .25, .25, .50, 1.0, 2.0, 4.0, 20 nmi.
  - Rings accuracy: ±0.03 nmi or ± 1% of scale in use, whichever is greater
  - Marker Available Range: 0.15 to 120 nmi.
  - Marker Accuracy: ± 0.02 nmi or ± 1% of scale in use, whichever is greater
- Bearing:
  - Accuracy: Better than 1°
  - Resolution: 0.8 °
- Controls:
  - Scale, gain, anti-clutter sea (STC), anti-clutter sea range -1,2, anti-clutter rain (FTC), marker, cursor, dimmer, plotter dimmer, sweep intensity, rings intensity, market intensity, marker read out, bearing, heading, power, power pulse, azimuth, shift (up-down, left-right), defruiter, stern flash, circular polarization, performance marker, electronic cursor, log amp, anti-clutter auto

1.2 Transmitter Unit

- Peak Power: 50 kW
- Frequency: 9375 MHz ± 30 MHz
- Pulse length and pulse repetition rates:
  - 0.07 us, 4000 pps (0.25, 0.5, 1.5 nmi ranges)
  - 0.25 us, 2000 pps (3, 6, 12 nmi ranges; with power pulses ON, 0.25 to 1.5 nmi Ranges)
  - 1.2 us, 500 pps (24, 48, 120 nmi ranges, with power pulse ON, 3 to 12 nmi ranges.

1.3 Receiver Unit

- Characterization: Log amp. and Linear amp.
- IF: 60 MHz
- IF bandwidth: 17 MHz at 0.07 us and 0.25 us pulse width
  3 MHz at 1.2us pulse width
- Noise Factor: Better than 8.5 dB.
- Tuning: Manual with LED tuning display

1.4 Antenna Unit (9 Foot):

- Horizontal beamwidth: 0.8°
- Vertical beamwidth: 25°
- Side-lobe level within ± 10° of main beam: less than -27 dB
- Portion that exceeds ±10° of main beam: less than -30 dB
- Polarization: Horizontal or Circular
- Rotation speed: 22 RPM

2 SPERRY 340X RADAR (CAS)

2.1 Processing and Display Unit

- E2756PLB 16 inch (40 cm) PPI tube
- Mechanical and Electronic Bearing Line (EBL) cursor
- Fixed and movable double azimuth ring with bearing ring stabilization adapter
- Flat face type reflector plotter
- Full ARPA features available
- Range:

  Scale: 0.25, 0.5, 1.5, 3, 6, 12, 24, 48, 120 nmi
  Rings interval: 0.05, 0.1, 0.25, 0.25, 0.5, 1, 4, 8, 20 nmi
  Rings Accuracy: ± 0.3 nmi or 1% of scale in use, whichever is greater

  Marker available range: 0 to 120 nmi
  Marker accuracy: ± 0.02 nmi or ± 1% of scale in use, whichever is greater
  Maximum range: Better than 20m.
  Resolution: Better than 15m.

- Bearing:

  Accuracy: Better than 1°
- Controls:

  Power, range, tuning, gain, anti-clutter sea, anti-clutter rain, AC range, power pulse, video exporter, RIC, heading, north up, sweep intensity, rings intensity, read out, dim, plot, off center, VRM-1, VRM-2, VRM intensity, EBL, origin, offset, EBL intensity, joystick, cursor, azimuth, shift, anti-clutter auto, log amp.

2.2 Transmitter Unit

- Peak Power: 50 kW
- Frequency: 9375 MHz ± 30 MHz
- Pulse length and repetition rates:

  0.07 us, 3200 pps (0.25, 0.5, 0.75, 1.5 nmi ranges)
  0.25 us, 1600 pps (3, 6, 12 nmi ranges; with power pulse ON, 0.25 to 1.5 nmi ranges)
  1.2 us, 530 pps (24, 48, 120 nmi ranges, with power pulse ON, 3 to 12 nmi ranges)

2.3 Receiver Unit

- Characterization: Log amp and linear amp.
- IF: 60 MHz
- If bandwidth: 17 MHz at 0.07 us and 0.25 us pulse width
  3 MHz at 1.2 us pulse width.
- Noise factor: Better than 8.5 dB
- Tuning: Manual with LED tuning display

2.4 Antenna Unit (9 foot)

- Horizontal beamwidth: 0.8°
- Vertical beamwidth: 25°
- Side lobe level within ± 10° of main beam: less than -27 dB
- Portion that exceeds ± 10° of main beam: less than -30 dB
- Polarization: Horizontal
- Rotation speed: 22 RPM

3 RAYTHEON PATHFINDER ST RASTER SCAN RADAR

3.1 Processing and Display Unit

- M34 Raster display CRT, 23 inch (34 cm) diagonal
- Resolution: 1024 x 0768 lines
- Electronic bearing line cursor
- Gyro stabilizated azimuth ring
- Full ARPA features available
- Range:
  Scale: 0.25, 0.5, 0.75, 1.5, 3, 6, 12, 24, 48, 96 nmi
  Range ring accuracy: 0.3% or 7 metres, whichever is greater
  Range resolution: 0.3% or 4 metres, whichever is greater
  Minimum range: 25 metres
- Bearing:
  Cursor bearing readout resolution: 0.01 nmi up to 10 nmi, 0.1 nmi up to 96 nmi
  Accuracy: 1°

- Controls:
  Power, self-test, gain, tune, anti-sea clutter, anti-rain clutter and FTC rate, range, pulse width. Performance monitor function, variable range marker brilliance, range ring brilliance, true wakes, background noise level, relative/true motion, heading line, fast target brilliance, interference rejection function, heads up/north up, ship's heading, manual/ship's log speed, data entry functions, cursor control functions

3.2 Transmitter Unit

- Peak power: 25 KW
- Frequency: 9410 MHz ± 30 MHz
- Pulse length and pulse repetition rates:
  0.08 us at 3000 pps
  0.25 us at 2000 pps
  0.75 us at 1000 pps
  1.0 us at 750 pps

3.3 Receiver Unit

- IF: 60 MHz
- Bandwidth (3 dB): 20, 6, 4, 4, MHz corresponding to pulse lengths and pulse repetition rates given above
- Noise figure: 7.5 dB

3.4 Antenna Unit (7 foot)

- Horizontal Beam width: 1°
- Vertical beam width: 25°
- Horizontal side lobes: -32 dB
- Gain: 28.5 dB
- Polarization: horizontal
- Rotation speed (60 Hz): 26 RPM

APPENDIX H

NIGHT VISION GOGGLE SYSTEMS

BROCHURES

LITTON MODEL M-927 AVIATOR'S NIGHT VISION SYSTEM

ANVIS—The First Night Vision System Designed Specifically for Aviators.

The night vision goggle has dramatically extended the helicopter's operational mission capability. A pilot can now carry out search and rescue operations and even missions flying nap-of-the-earth under moonlight or starlight conditions. Based on the experience of developing and producing night vision goggles for almost a decade, Litton is producing the ANVIS goggle, designed specifically for aviators.

Features

- NORMAL PERIPHERAL VISION Allows use of unintensified peripheral cues helpful during flight. Eliminates tunnel vision. Permits easy lookdown for reading maps and to monitor the instrument panel.
- SATISFIES MILITARY SPECIFICATIONS Rugged construction. Reliable and easily maintained. Logistical support available.
- MINIMIZES FATIGUE Lightweight design. Powerpack counterbalances goggle assembly for a more equal weight distribution.
- FLIP-UP STOWAGE Pilot can instantly change from night vision mode to unaided viewing.
- GREATER SENSITIVITY Improved contrast with Gen 2^{plus} or Gen 3 image intensifier tubes.
- FAST FLASH RESPONSE With Gen 2^{plus} tubes the image stays clear and bright, even when exposed to flares or light flashed directly in the field of view.
- EASY TO ADJUST All essential adjustments can be made with the left hand, freeing the right hand to operate the aircraft.
- SIMPLE TO UPGRADE Goggles can be easily upgraded from Gen 2^{plus} model M-927 to Gen 3 model M-929 by a simple tube replacement.
- CRASH BREAKAWAY/ONE HAND POP-OFF Fast removal provides for pilot safety in a critical situation.
- DAYLIGHT TRAINING ACCESSORIES Permits daylight training with complete safety.
- SYSTEM REDUNDANCY Provides high safety and reliability.
- DESIGNED TO FIT THE SPH-4 US ARMY AVIATORS HELMET Can be adapted to other US and foreign aviator helmets.
- LOGISTICS SPARES SUPPORT Readily available spares provisioning.
- OBJECTIVE LENS DESIGN The objective lens utilizes integrated minus blue-green filtering, which is compatible with the new blue-green cockpit lighting.

Applications

- Covert night combat
- Nap of the earth flying
- Border patrol
- Search and rescue
- Engagement and support
- Troop transport
- Reconnaissance
- Minesweeping
- Navigation

Enhanced Sensitivity

The Litton M-927 Aviator's Goggle offers substantial improvements over earlier night vision systems. Foremost is its increased sensitivity, with Gen 2^{plus} or Gen 3 image intensifier tubes, providing the pilot with much higher system resolution and greater contrast, even in starlight. Missions that would previously have been cancelled can now be performed.

Along with its increased sensitivity, the Litton M-927 ANVIS goggle offers improved flash response. The image detail stays clear and bright, even when flares or bright lights enter into the field of view.

LITTON MODEL M-912A/M-915A
HIGH PERFORMANCE NIGHT VISION GOGGLE

Image Intensifier

The M-912A utilizes two 2nd Gen wafer type image intensifier tube assemblies, each having an 18mm image format. Each assembly has its own power supply to provide redundancy for improved reliability.

The M-915A is a high performance version of the M-912A and employs two 18mm Gen 2^{plus} image intensifier assemblies which gives the system three times the system gain of the standard AN/PVS-5A, and a dramatic increase in useful range.

The improved flash performance and extended dynamic range of the M-915A allows its use under field conditions previously too harsh for night vision systems. The image detail stays clear and bright, even when flares or bright lights are flashed directly into the field of view.

Typical System Characteristics	Values	Units
General		
Magnification	1.0X	
Field of view	40	degrees
Resolution (limiting)	.68	Lp/mR
Brightness gain (M-912A)	1000	
(M-915A)	1700	
Weight	960	grams
Objective Lens		
Focal Length	26.8	mm
F/Number	1.1	
T/Number	1.2	
Focus Range	25 to infinity	cm
Eyepiece		
Effective Focal Length	27.0	mm
Diopter Range	−6 to +2	diopter
Eye Relief Distance	15.0	mm
Interpupillary	51 to 72	mm

Electrical

Power source: (2) 1.5 V Alkaline Batteries
Operating life: 40 hours @ 23 degrees C

Environmental

Temperature,
operation: −51 degrees C to +49 degrees C
storage: −51 degrees C to +68 degrees C
Humidity: 95% @ +68 degrees C
Water Immersion: 1m for 30 min.

Standard Accessories

Night Vision Goggles, black with neck cord
Carrying Case, Polycarbonate plastic, black with strap
Head strap, black
Instruction Manual
Lens Cleaning Tissue
Hexagonal Wrench key, .050"
Batteries, two BA-3058/U
Lens Protective Caps

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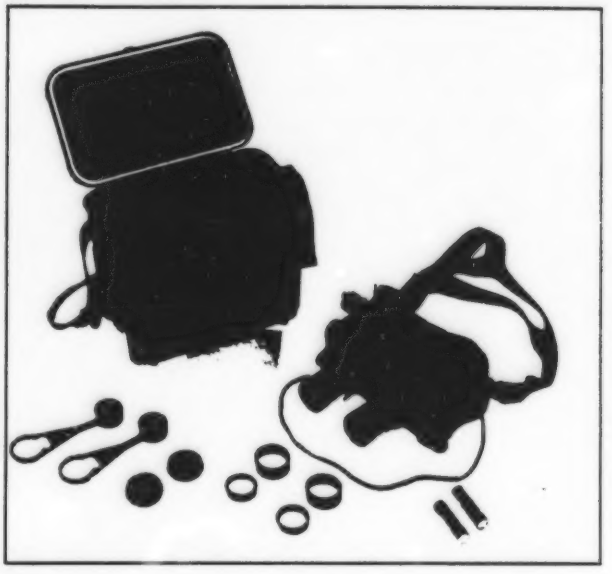
Optional Equipment

Shipping Storage Case
Demisting Shields
Daylight Training Filters (2)
Lithium AA Batteries
Sacrificial Filters (2)
Soft Carrying Case



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LITTON MODEL M-927 AVIATOR'S NIGHT VISION SYSTEM

ANVIS—The First Night Vision System Designed Specifically for Aviators.

The night vision goggle has dramatically extended the helicopter's operational mission capability. A pilot can now carry out search and rescue operations and even missions flying nap-of-the-earth under moonlight or starlight conditions. Based on the experience of developing and producing night vision goggles for almost a decade, Litton is producing the ANVIS goggle, designed specifically for aviators.

Features

- NORMAL PERIPHERAL VISION Allows use of unintensified peripheral cues helpful during flight. Eliminates tunnel vision. Permits easy lookdown for reading maps and to monitor the instrument panel.
- SATISFIES MILITARY SPECIFICATIONS Rugged construction. Reliable and easily maintained. Logistical support available.
- MINIMIZES FATIGUE Lightweight design. Powerpack counterbalances goggle assembly for a more equal weight distribution.
- FLIP-UP STOWAGE Pilot can instantly change from night vision mode to unaided viewing.
- GREATER SENSITIVITY Improved contrast with Gen 2^{plus} or Gen 3 image intensifier tubes.
- FAST FLASH RESPONSE With Gen 2^{plus} tubes the image stays clear and bright, even when exposed to flares or light flashed directly in the field of view.
- EASY TO ADJUST All essential adjustments can be made with the left hand, freeing the right hand to operate the aircraft.
- SIMPLE TO UPGRADE Goggles can be easily upgraded from Gen 2^{plus} model M-927 to Gen 3 model M-929 by a simple tube replacement.
- CRASH BREAKAWAY/ONE HAND POP-OFF Fast removal provides for pilot safety in a critical situation.
- DAYLIGHT TRAINING ACCESSORIES Permits daylight training with complete safety.
- SYSTEM REDUNDANCY Provides high safety and reliability.
- DESIGNED TO FIT THE SPH-4 US ARMY AVIATORS HELMET Can be adapted to other US and foreign aviator helmets.
- LOGISTICS SPARES SUPPORT Readily available spares provisioning.
- OBJECTIVE LENS DESIGN The objective lens utilizes integrated minus blue-green filtering, which is compatible with the new blue-green cockpit lighting.

Applications

- Covert night combat
- Nap of the earth flying
- Border patrol
- Search and rescue
- Engagement and support
- Troop transport
- Reconnaissance
- Minesweeping
- Navigation

Enhanced Sensitivity

The Litton M-927 Aviator's Goggle offers substantial improvements over earlier night vision systems. Foremost is its increased sensitivity, with Gen 2^{plus} or Gen 3 image intensifier tubes, providing the pilot with much higher system resolution and greater contrast, even in starlight. Missions that would previously have been cancelled can now be performed.

Along with its increased sensitivity, the Litton M-927 ANVIS goggle offers improved flash response. The image detail stays clear and bright, even when flares or bright lights enter into the field of view.

LITTON MODEL M-927
AVIATOR'S NIGHT VISION SYSTEM

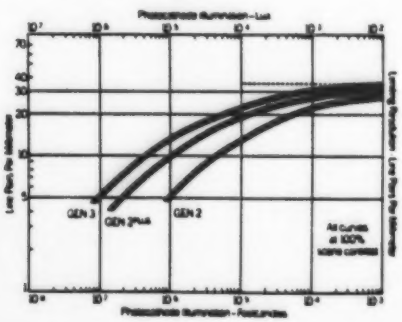
Greater Comfort and Visibility

The Litton M-927 goggle mounts to a single point on the helmet visor guard. No face mask is required. The pilot can monitor his instruments by looking under or around the goggle. The absence of a face mask permits practically normal peripheral vision.

Another convenience is the "flip-up" stowage feature. The binocular assembly can be pivoted out of the way whenever the pilot wants to make use of natural or artificial illumination.

The Litton goggle is designed to minimize wearer fatigue. The weight of the binocular is counter-balanced by the dual battery power pack which is mounted at the rear of the helmet. The lighter overall weight also leads to greater comfort during missions of long duration.

System	Values	Units
Characteristics		
Field of View	40	Degrees
Magnification	1 x ±5	%
Distortion	less than 4	%
Resolution, on Axis (min)		
Gen 2^{plus} (M-927)	0.68	1p/mR
Gen 3 (M-929)	0.76	1p/mR
Brightness Gain		
Gen 2^{plus} (M-927)	1,200	ft-L/ft-L(nom.)
Gen 3 (M-929)	2,000	ft-L/ft-L(nom.)
Binocular Assembly weight	456	grams (apprx)
Visor Mount Assembly weight	200	grams (apprx)
Controls and Adjustments		
On/Off/On switch to provide for selection of either of two batteries in battery pack		
Objective, Focus Range	25 to infinity	cm
Eyepiece, Diopter Range	−6 to +2	Diopter
Interpupillary Adjustment Range	51 to 72	mm
Vertical Adjustment Range	16	mm
Fore/Aft Adjustment Range	16	mm
Tilt Adjustment Range	8	Degrees (min.)



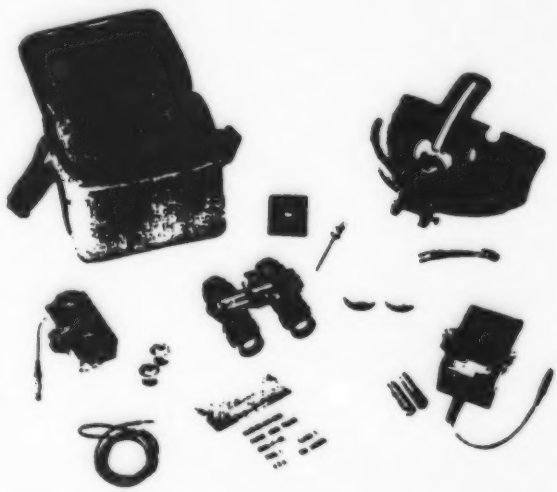
Battery Pack	Type BB	Type AA
Battery type	BA-1567/u, Mercury or BA-5567/u, Lithium	"AA" Carbon/ Zinc or "AA" Alkaline or BA-3058/u
Batteries per pack	2	4
Battery pack weight (including batteries)	177 grams	385 grams (apprx)
Auxiliary Voltage (from aircraft converter)	3.7 to 3.9 VDC	3.7 to 3.9 VDC

Environmental

Temperature, operation: −35°C to +49°C;
storage: −35°C to +68°C
Temperature shock: +68°C to +23°C and +23°C to −35°C
Max. Altitude, operation: 15,000 feet; storage 50,000 feet
Humidity: no detrimental effect at greater than 95% RH
Vibration: 5 to 600 Hz at up to 0.5g

The Litton aviator's goggle is available with either Gen 2^{plus} or Gen 3 image intensifier tubes. Upgrading from Gen 2^{plus} (M-927) to Gen 3 (M-929) is possible since the tubes are totally interchangeable.

The ANVIS Night Vision goggles are designed to meet the requirements of covert night aviation under almost any nighttime condition.



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